1st AIAA CFD High Lift Prediction Workshop

JAXA Contribution to HiLiftPW-1: Computational Results Using UPACS and TAS code

Mitsuhiro MURAYAMA, Kentaro TANAKA, and Kazuomi YAMAMOTO

Aviation Program Group,

Japan Aerospace Exploration Agency (JAXA)

Computational results by JAXA

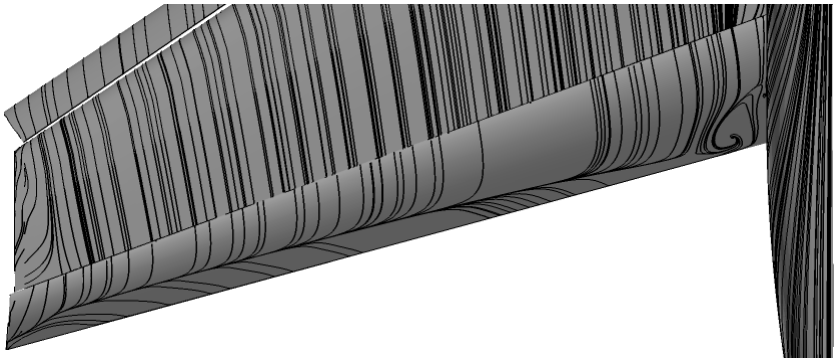
- Submitted data
  - Unstructured TAS and structured UPACS results using JAXA Self-generated grids

CFD Code	GridType	Grid	Turb. Model	Computation
TAS	Mixed-element Unstructured	JAXA Self-generated	SA	Case1
				Case2
				Case3
UPACS	Multi-block Structured	JAXA Self-generated	SA	Case1
				Case2

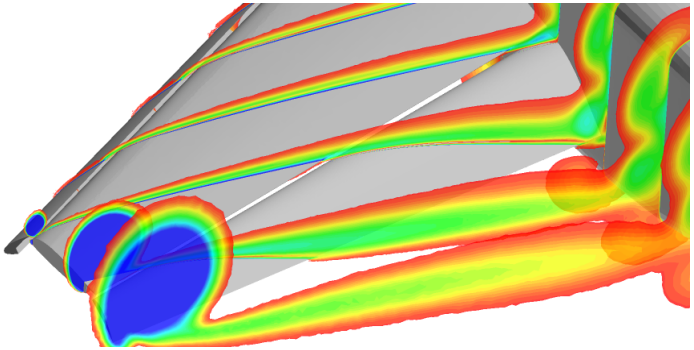
- Additional evaluations (Not submitted)
  - Comparison of unstructured grid generation method
    - JAXA Self-generated and Wyoming grids by TAS
    - Change of local grid densities on the flap trailing-edge
  - Comparison of turbulence model
    - Spalart-Allmaras model and Menter's SST model by TAS
    - Influence of modeling in Spalart-Allmaras model

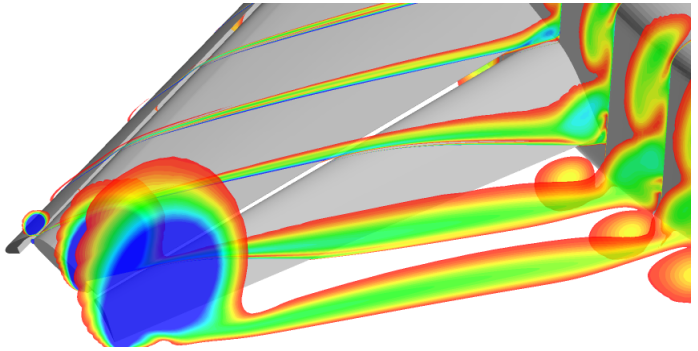
Focus of this presentation

- AOA=13
  - Influence of Flap trailing-edge (TE) flow separation



- AOA=28
  - Influence of Tip vortex behavior





Grid information of JAXA self-generated grids

JAXA Multi-Block Structured Grid (Gridgen)

	Nodes	Surf. Nodes	TE Cells
Coarse	12M	0.14M	11
Medium	37M	0.31M	16
Fine	124M	0.70M	24

Coarse & Fine grids ← Based on interpolation of Medium grid

Multi-grid "unfriendly"

Different from the gridding guideline

JAXA Mixed-element Unstructured Grid (MEGG3D)

	Nodes	Surf. Nodes	TE Cells
Coarse	6M	0.23M	1
Medium	15M	0.38M	1
Fine	37M	0.65M	1

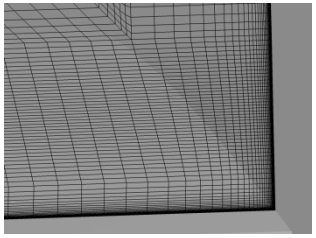
Cf. Wyoming Univ. Mixed-element Unstructured Grid (Provided by HiLiftPW)

	Nodes	Surf. Nodes	TE Cells
Coarse	4M	0.13M	>4
Medium	11M	0.28M	>6
Fine	32M	0.68M	>9

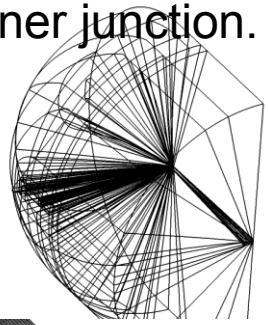
JAXA Multi-block Structured Grids (Gridgen)

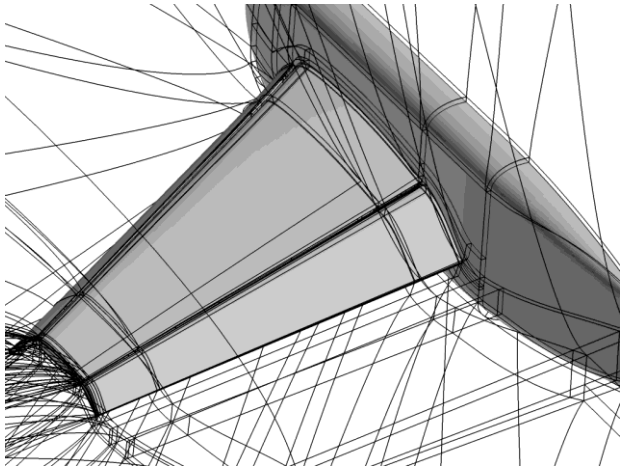
- Near the model surface:
  - O-O grid topology to guarantee better orthogonality within the boundary layer
- Outward:
  - C-O grid topology

High dense grid near the wing-fuselage corner junction.

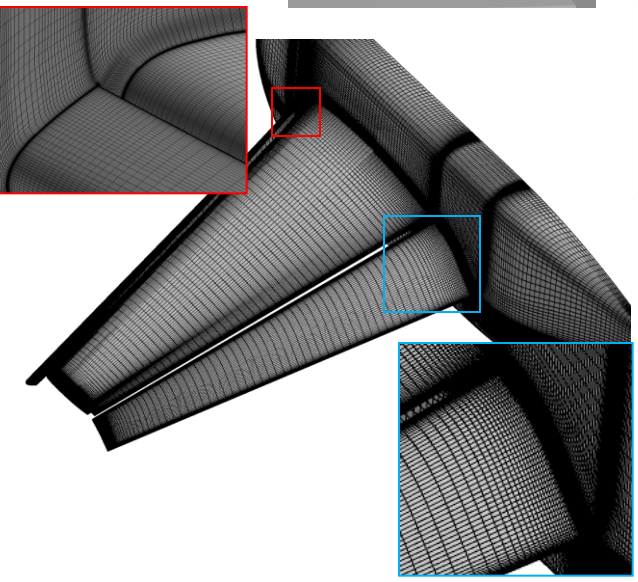


Wing-body juncture corner

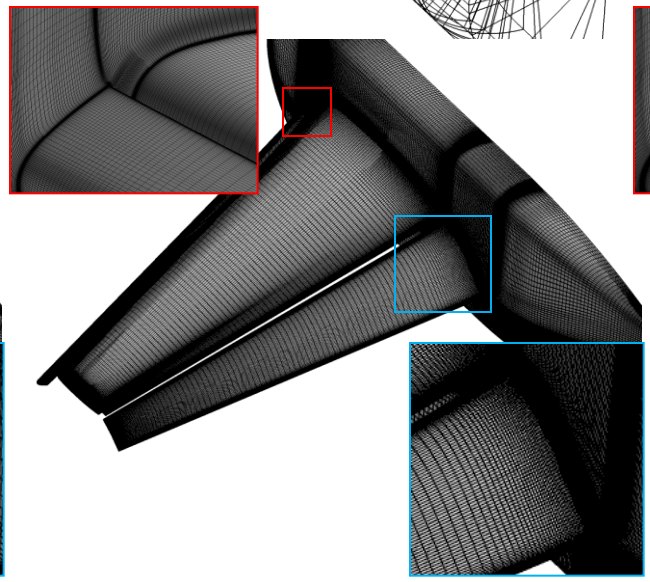




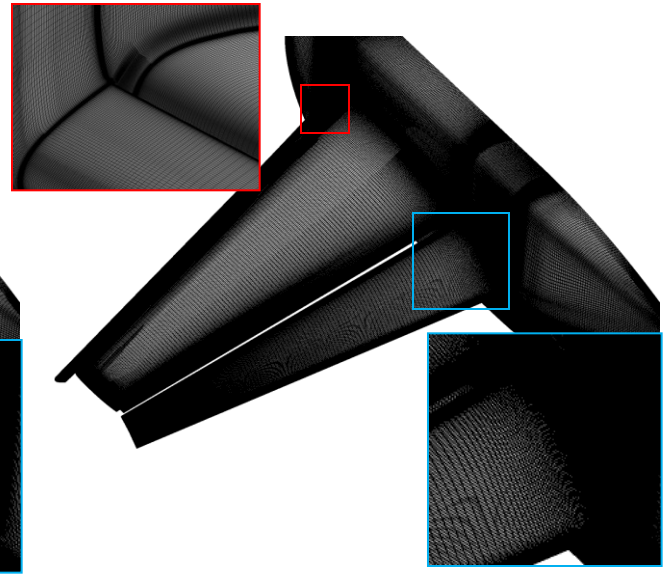
441 blocks



Coarse grid (12M)



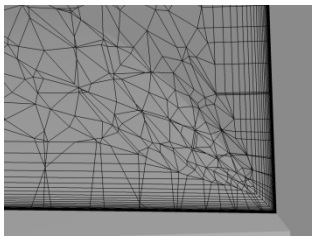
Medium grid (37M)



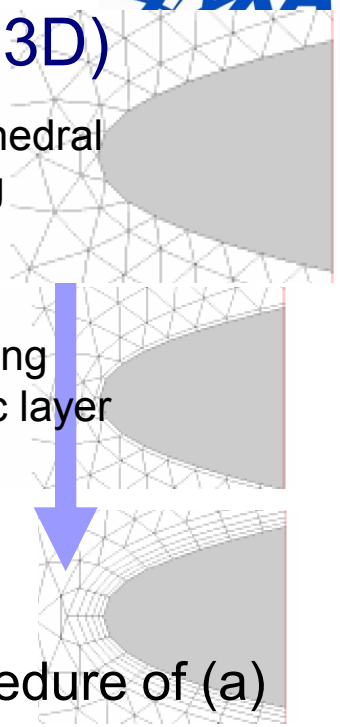
Fine grid (124M)

JAXA Mixed-element Unstructured grids (MEGG3D)

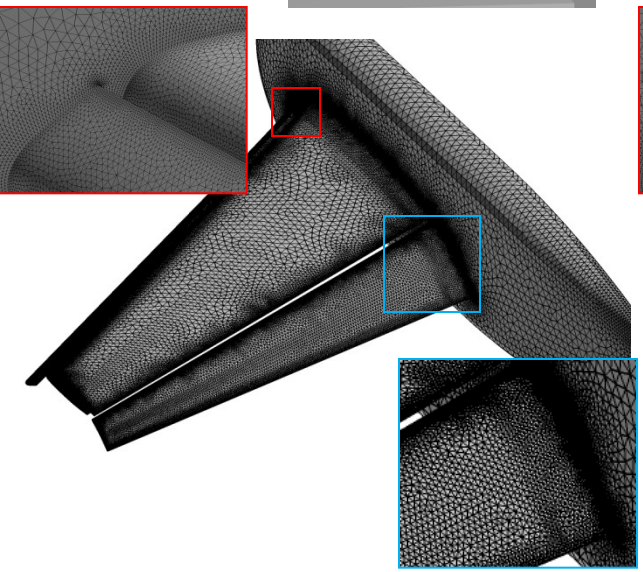
- Surface grid (Triangles)
  - Direct advancing front method employing nearly isotropic triangles
- Volume grid (Tetrahedra, Prisms, Pyramids): Option (a)
  - **(a) Delauney (tetra) → insertion of prismatic layer (prism)**
  - (b) Advancing front (tetra) → insertion of prism layer (prism)
  - (c) Advancing layer (prism) → Advancing front (tetra)



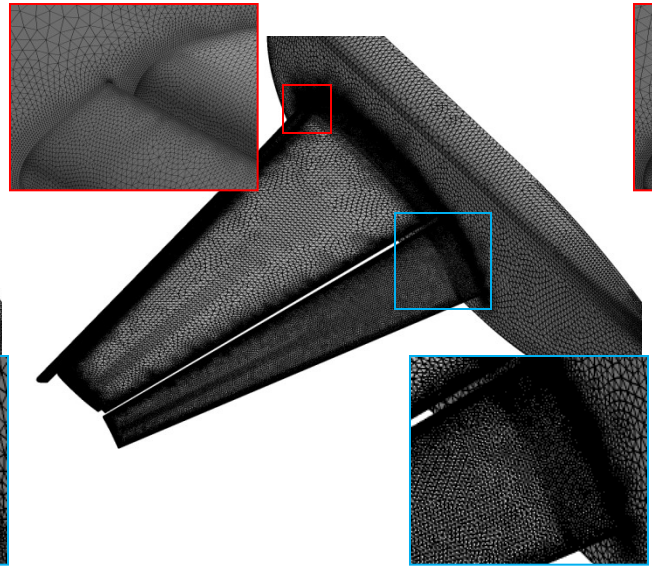
Wing-body juncture corner



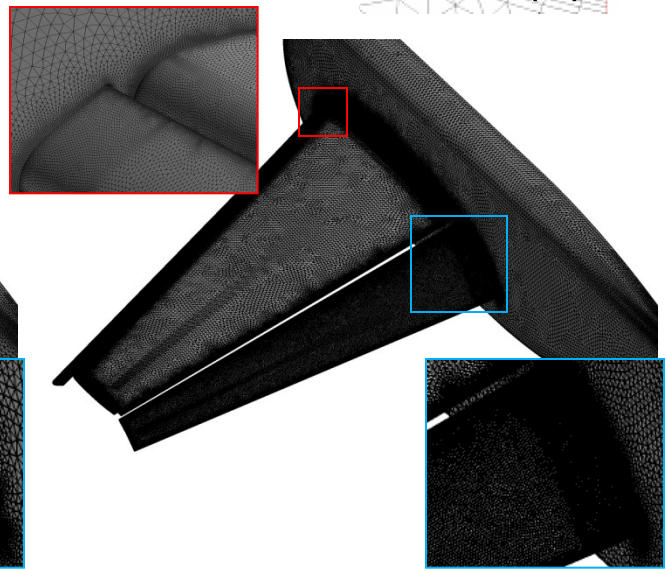
Procedure of (a)



Coarse grid (6M)



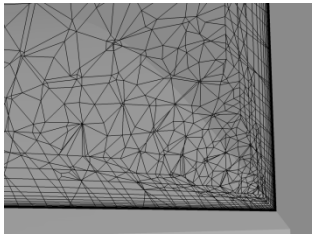
Medium grid (15M)



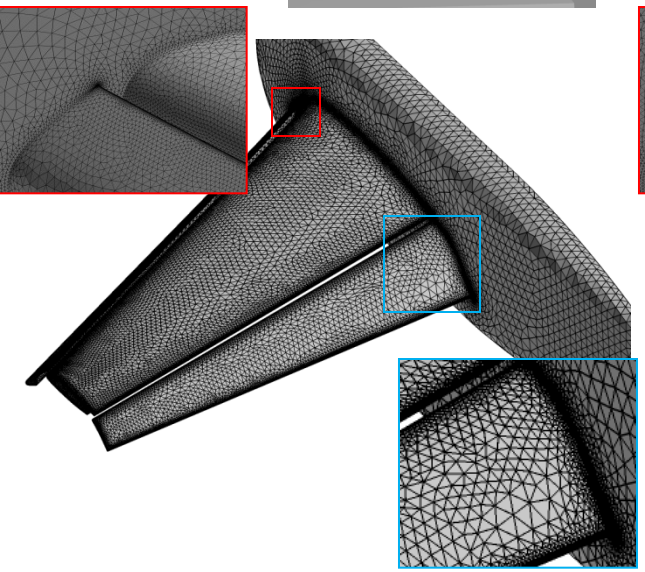
Fine grid (37M)

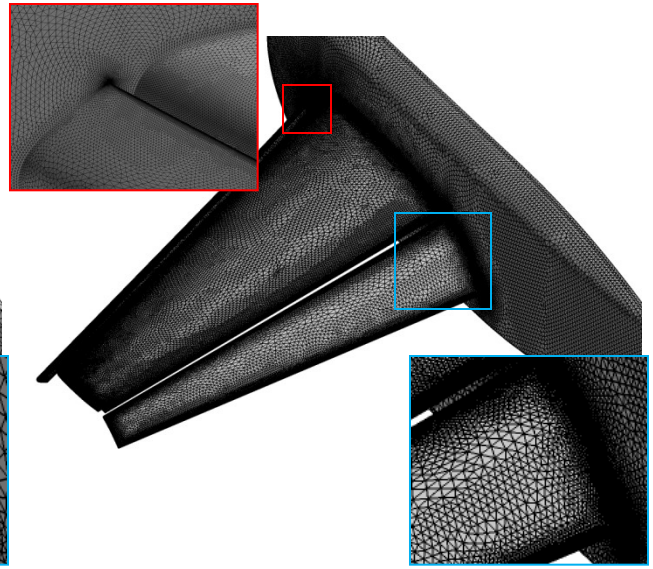
Wyoming Univ. Mixed-element Unstructured Grids

- Provided grid by HiLiftPW



Wing-body
juncture corner





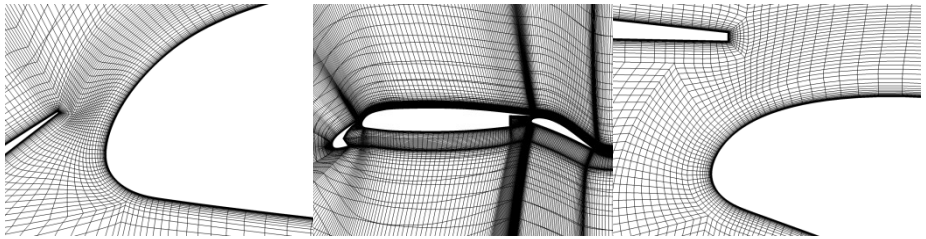
Coarse grid (3.7M)

Medium grid (11M)

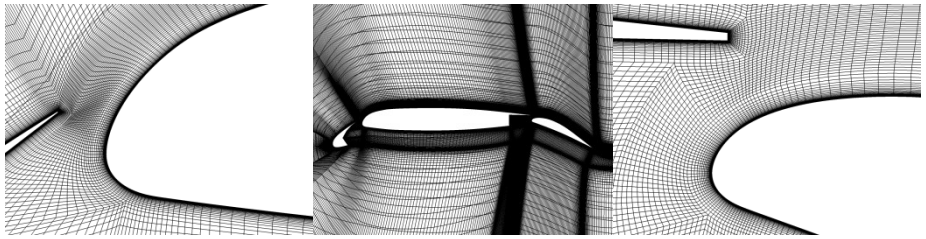
Fine grid (32M)

Comparison of cross-sectional view at 50% span

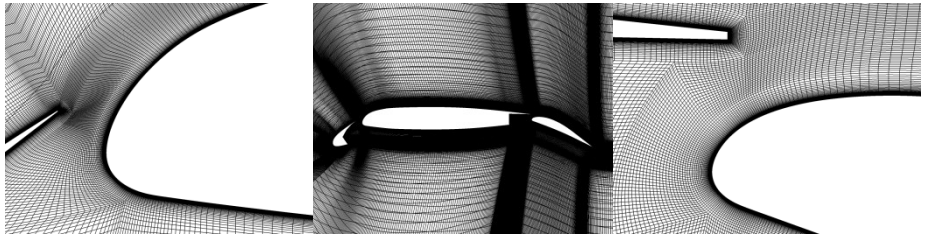
JAXA Structured Grid



Coarse

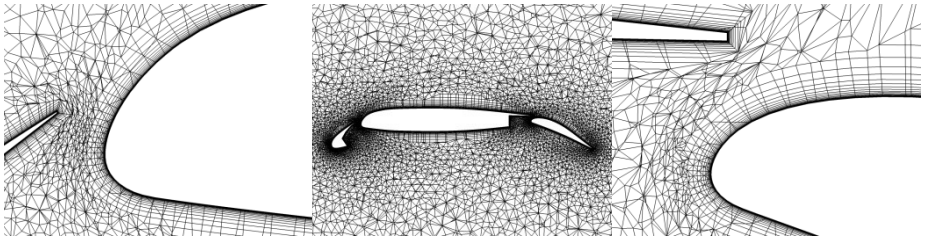


Medium

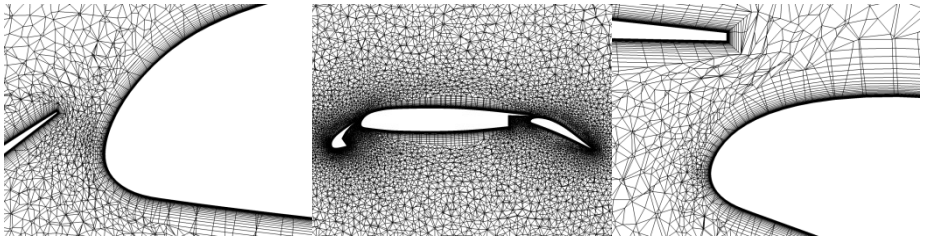


Fine

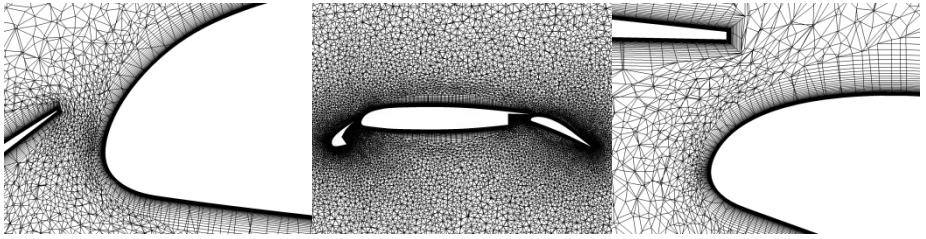
JAXA Unstructured Grid



Coarse



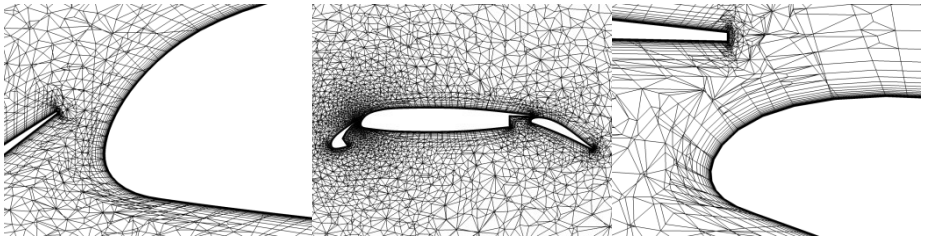
Medium



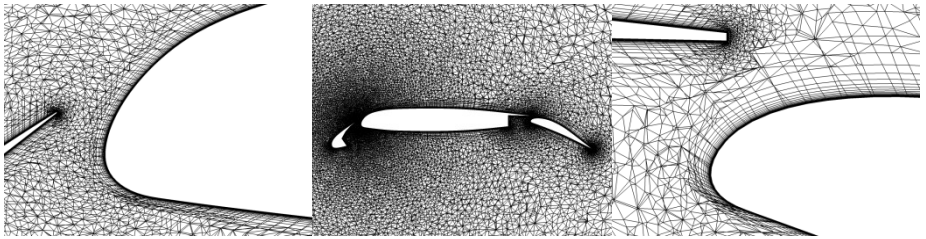
Fine

Comparison of cross-sectional view at 50% span

Wyoming Unstructured Grid



Coarse



Medium

Numerical methods: UPACS & TAS

	UPACS	TAS
Mesh type	Multi-block structured	Unstructured
Discretization	Cell-centered finite volume	Cell-vertex finite volume
Convection Flux	Roe 2nd-order (without Limiter)	HLLEW 2nd-order with Venkatakrishnan's limiter
Time integration	Matrix-Free Gauss-Seidel	LU-Symmetric Gauss-Seidel
Turbulence model	Spalart-Allmaras model	Spalart-Allmaras model

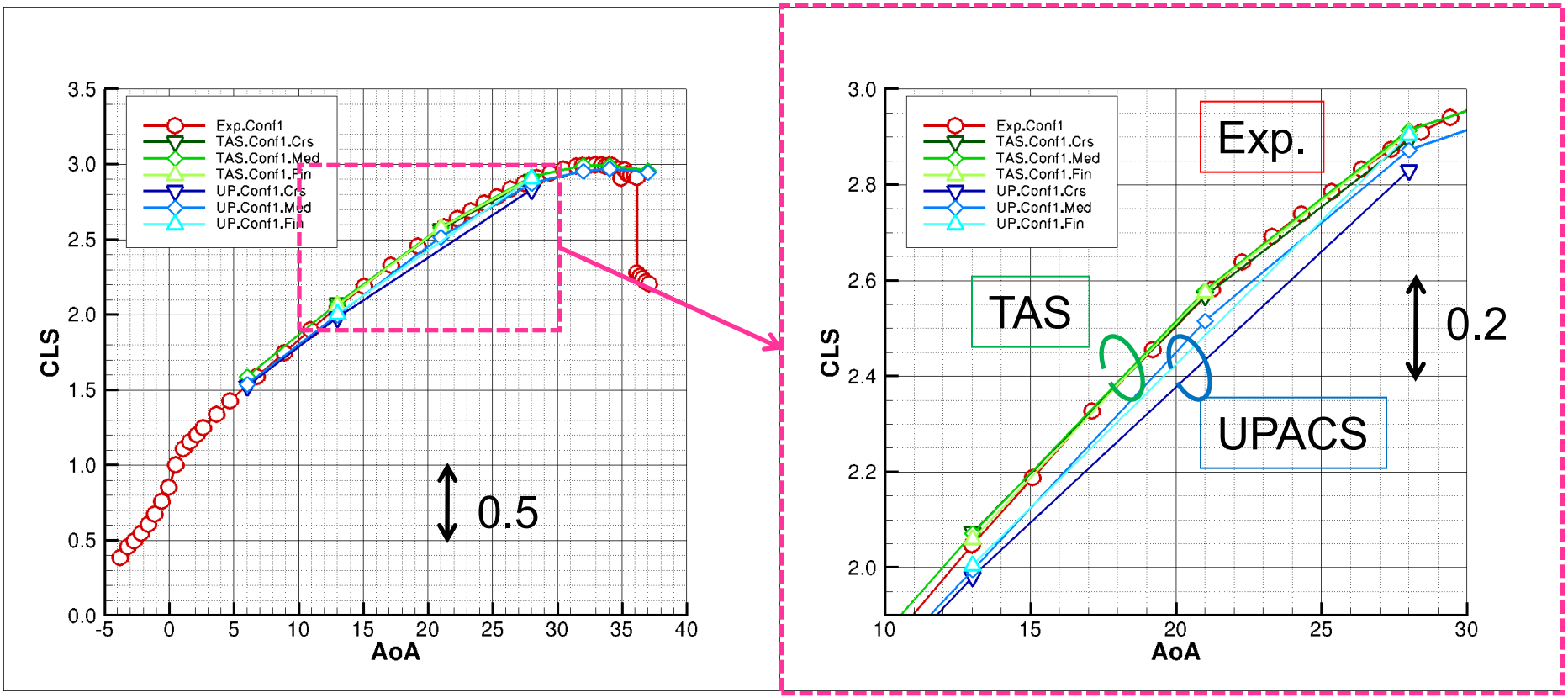
- Modification to the S-A model
  - without trip related terms
  - with a modification to production term: $S = \min(\sqrt{2\Omega}, \sqrt{2S^2})$
- Computer Platform: JSS - Fujitsu FX1 (SPARC64 VII 2.5GHz,3008cpu)
  - Typical computational time

Code	Grid points		# of CPU	CPU Time(H)	Tota lCPU Time(H)	# of Iteration
TAS	Medium	15M	48	30	1,440	50,000
UPACS	Medium	37M	48	80	3,840	100,000

- Case 1 Grid Convergence Study
- Case 2 Flap Deflection Prediction Study
- Case 3 Flap and Slat Support Effects Study

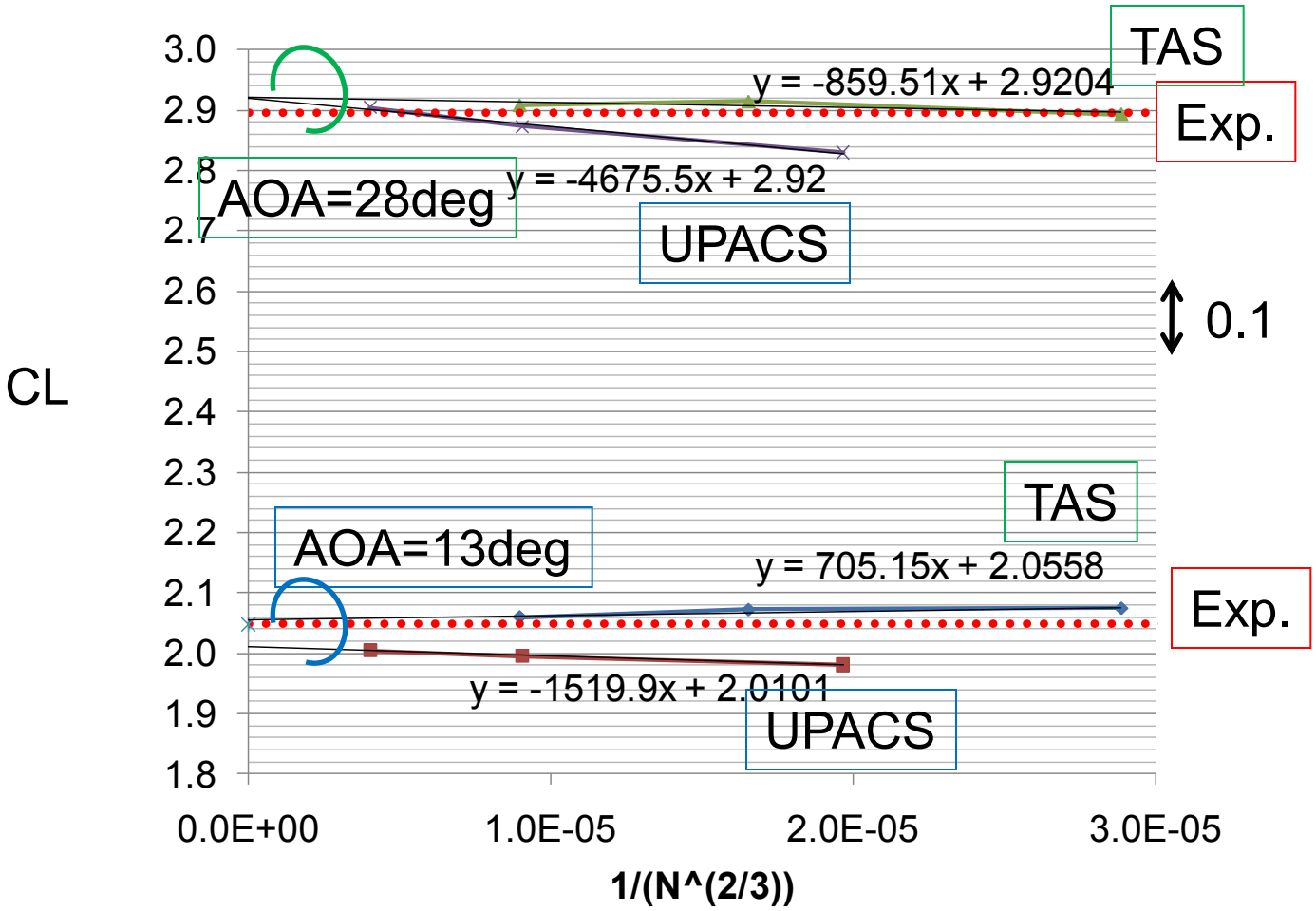
Case1:CL-alpha

- Good agreement with experimental results
- Lower CL by UPACS



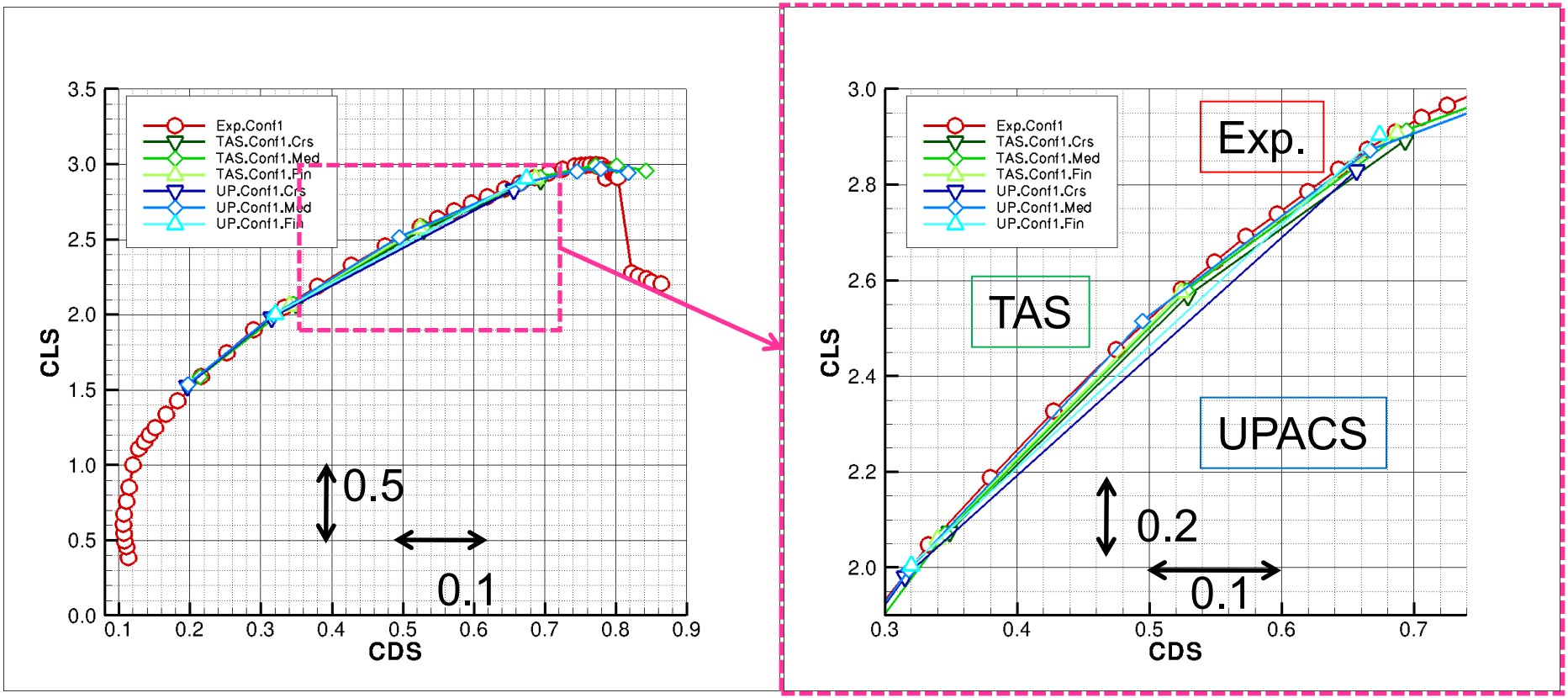
Case1:CL Grid Convergence

- Scattering by CFD code and grid density is within 0.1.
- AOA=28: Larger sensitivity to grid density by UPACS, identical converged CL
- AOA=13: Less sensitivity of grid density, difference of converged CL



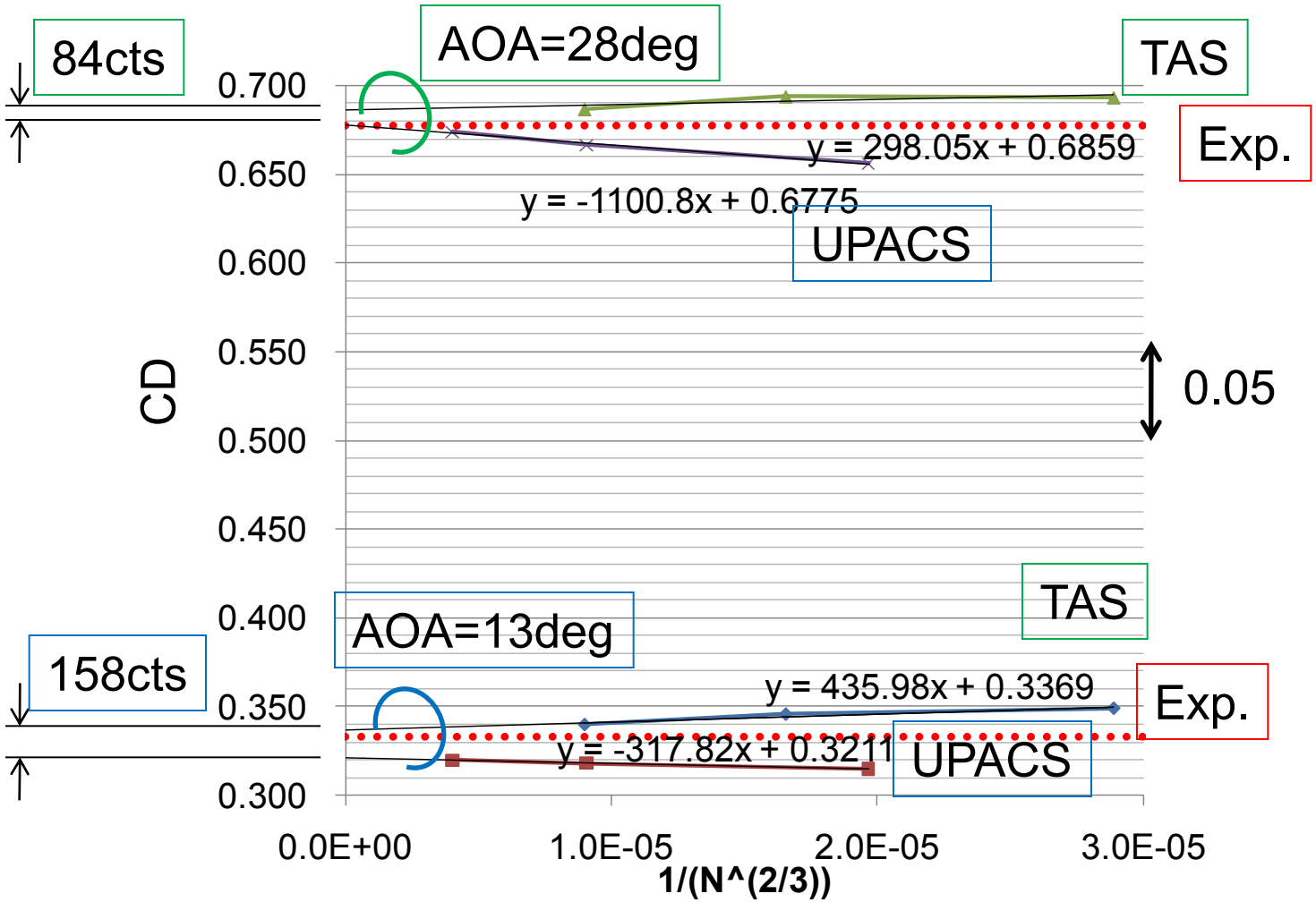
Case1:CL-CD

- Fair agreement with experimental results



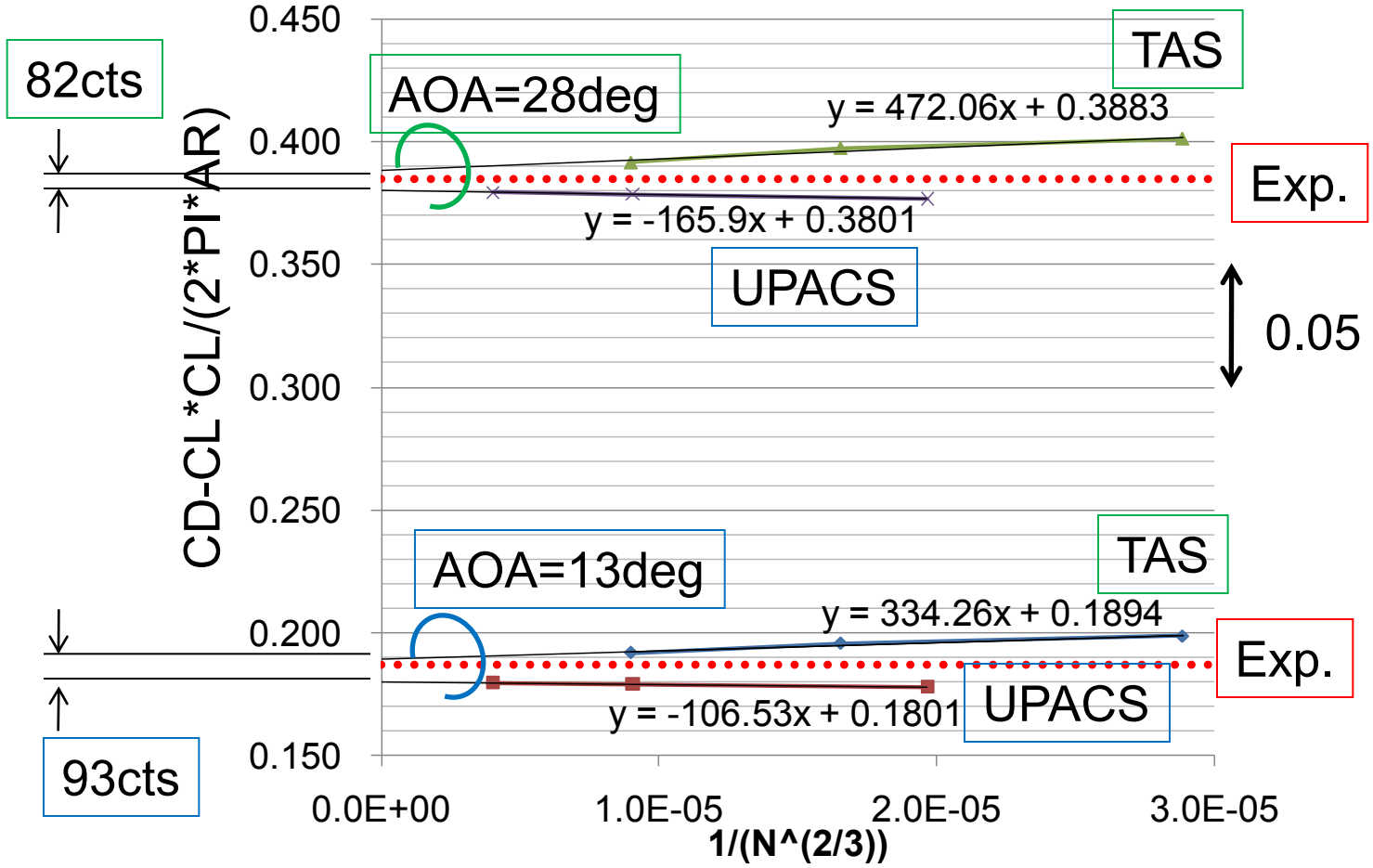
Case1:CD Grid Convergence

- This comparison includes influence of induced drag by the difference of lift prediction.



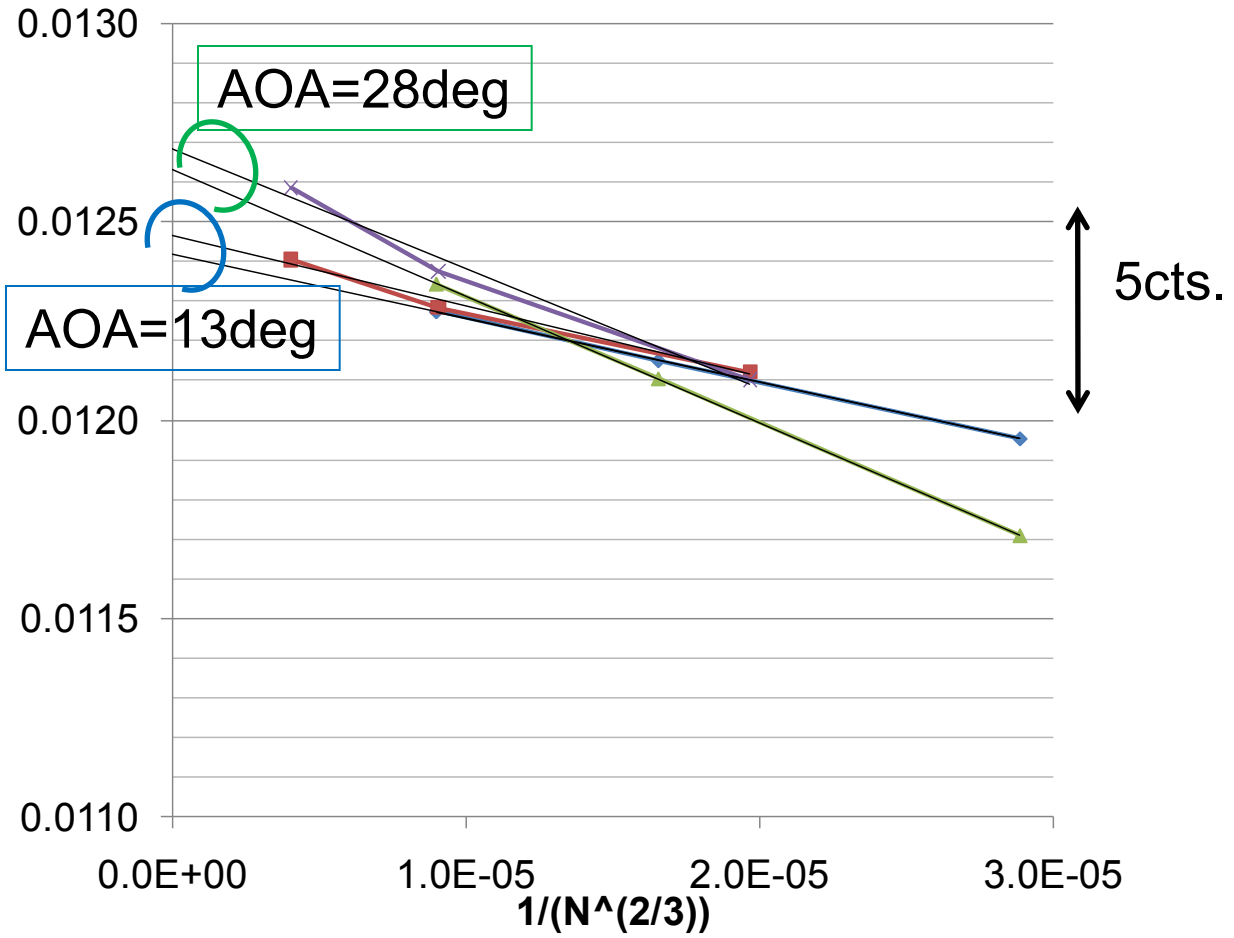
Case1:CD-$CD_{induced}$ Grid Convergence

- Ideal induced drag (=CL*CL/(2*Pi*AR)) is subtracted
- Differences of converged CD are by 80-90cts.



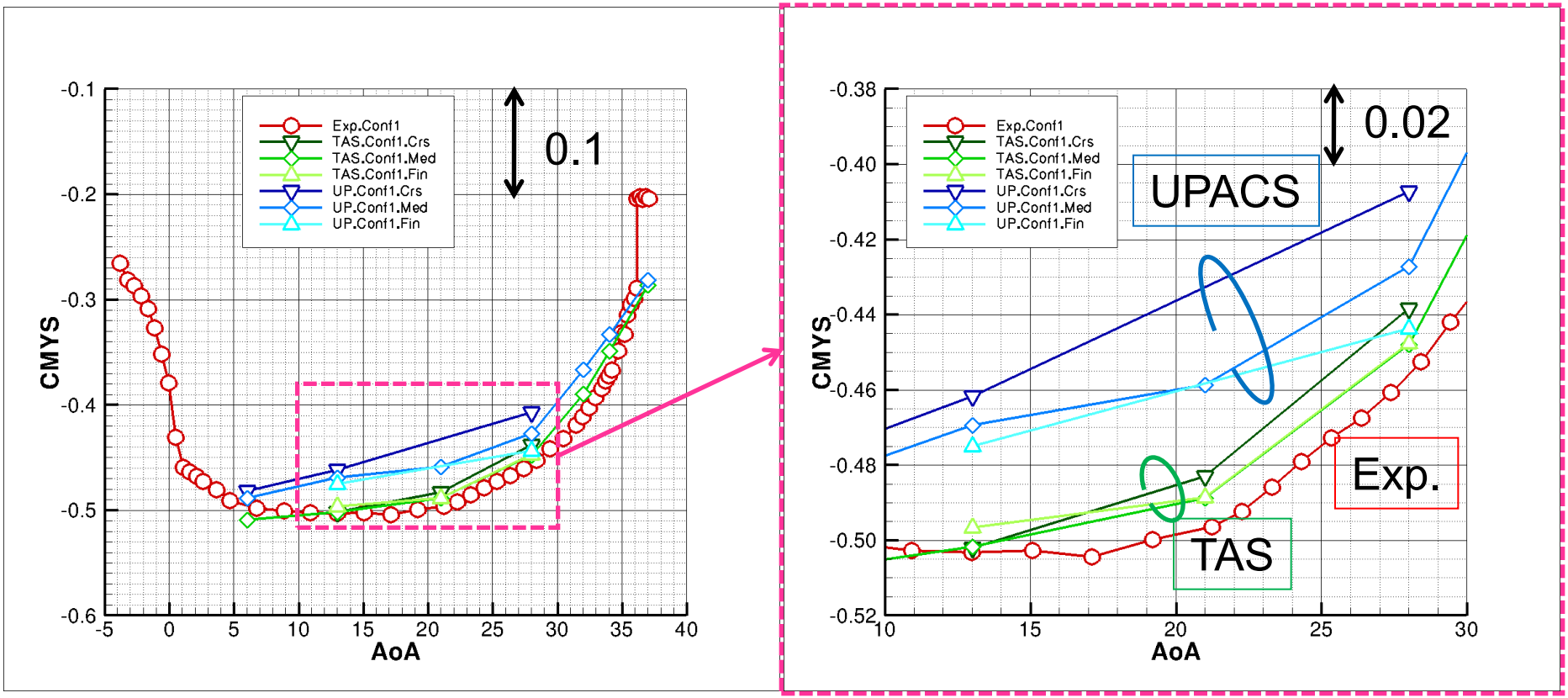
Case1:$CD_{friction}$ Grid Convergence

- Scattering by grid density is about 5cts. (0.15% of total drag at most).
- Differences of grid converged $CD_{friction}$ are within 1cts.



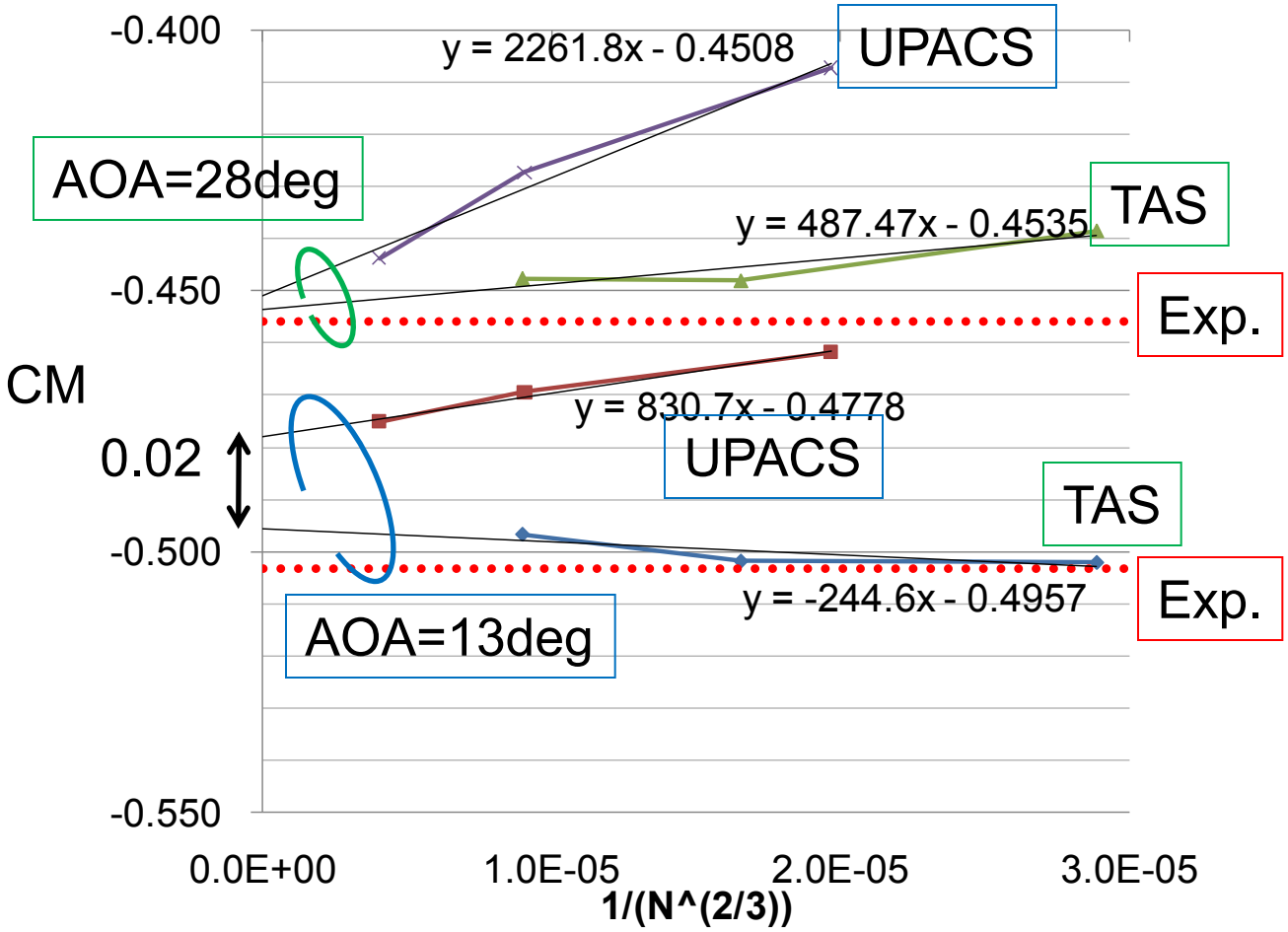
Case1:CM-alpha

- Fair agreement with experimental results by TAS
- Higher CM by UPACS especially at AOA=28



Case1:CM Grid Convergence

- Scattering by CFD code and grid density is 0.04.
- AOA=28: Larger sensitivity to grid density, identical converged CM
- AOA=13: Less sensitivity of grid density, difference of converged CM by 0.02



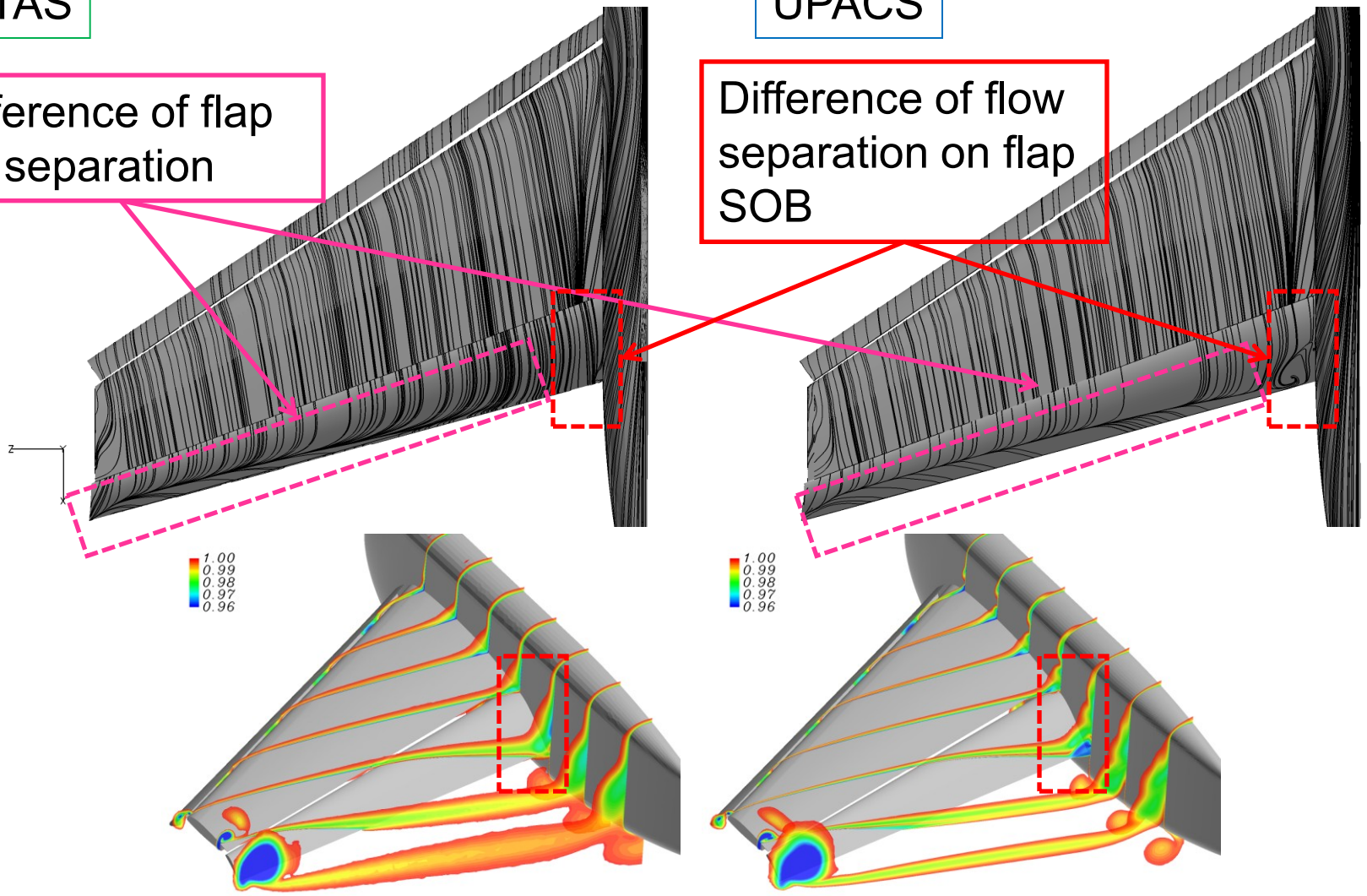
Case1:Oil flow and Ptotal (AOA=13, Medium)

TAS

UPACS

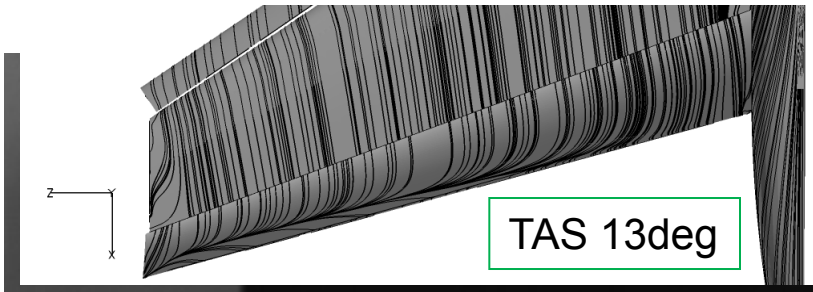
Difference of flap TE separation

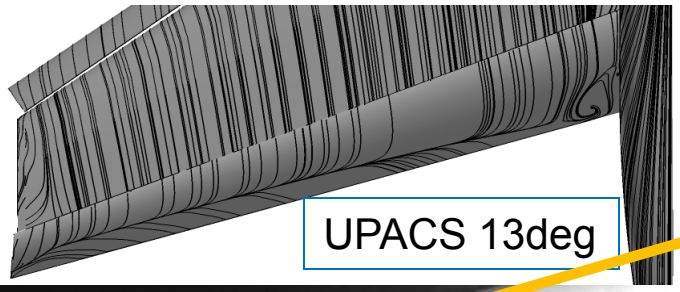
Difference of flow separation on flap SOB



Oilflow and Ptotal at α=13deg by Medium grid (Left:TAS, Right:UPACS)

Case1:Flap TE separation (AOA=13, Medium)





Result by UPACS seems to show larger flap TE flow separation than Exp.

Tuft image for the separation

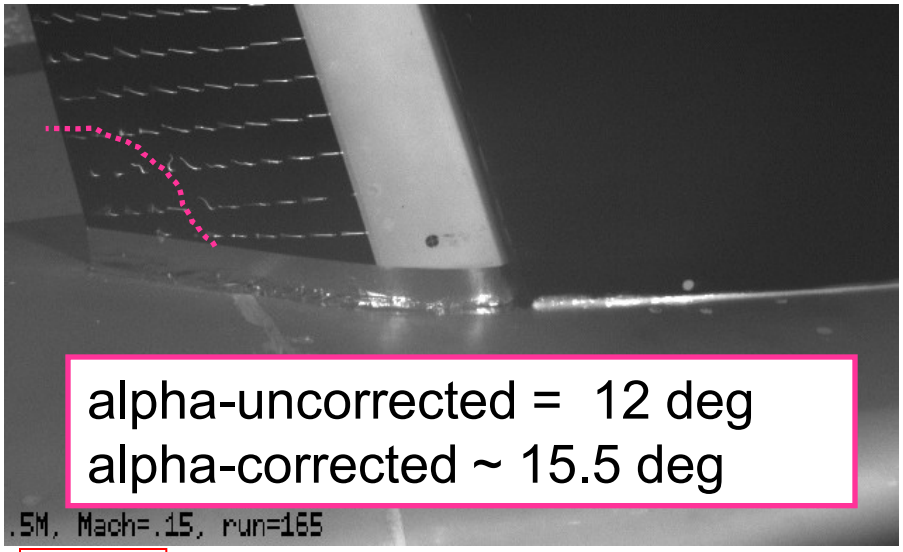
Flap LE

Flap TE

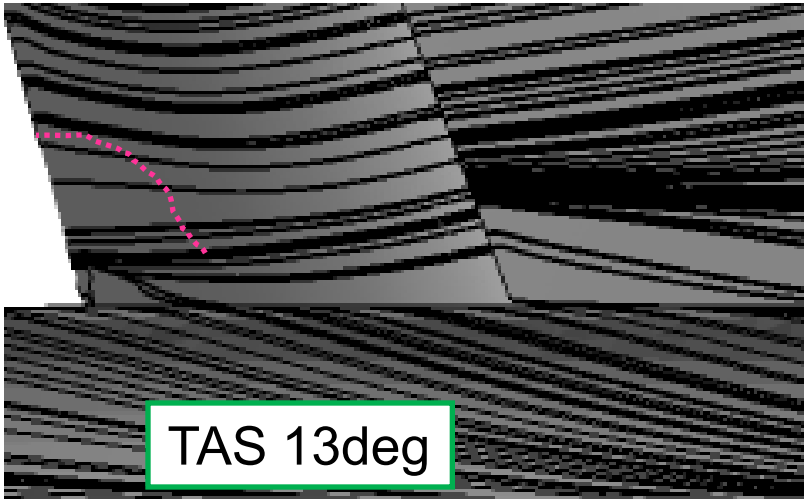
alpha-uncorrected = 12 deg alpha-corrected ~ 15.5 deg

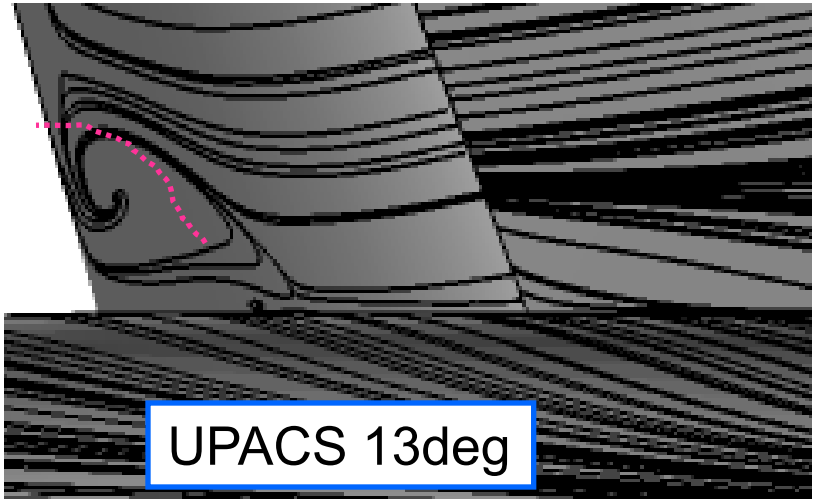
Exp.

Case1:Flap SOB separation (AOA=13, Medium)



Exp.



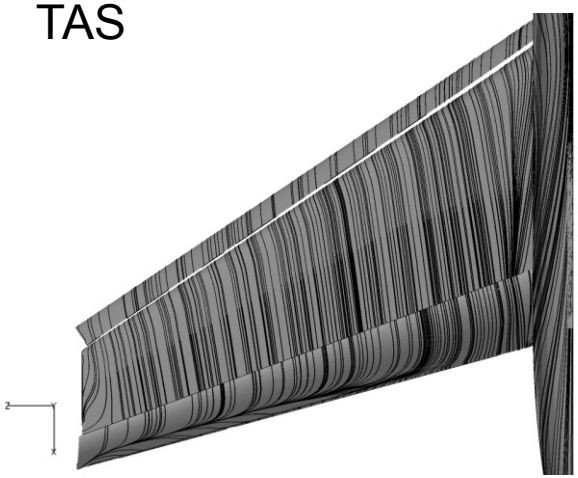


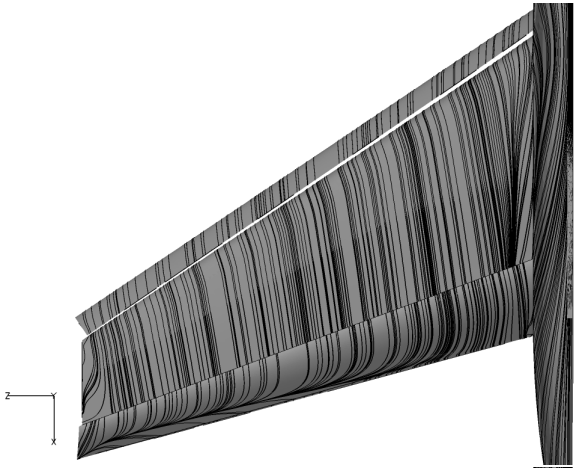
Flap SOB flow separation by UPACS shows better agreement with Exp.

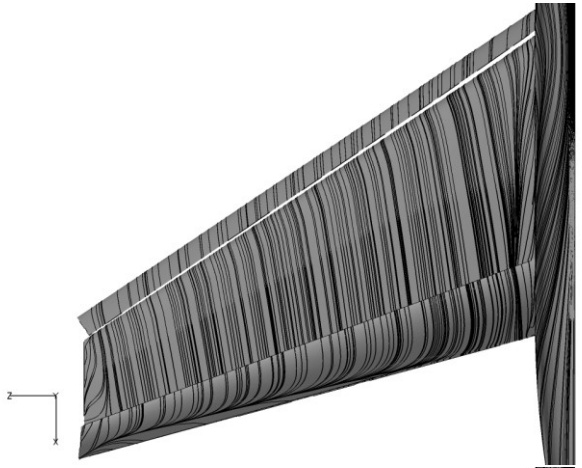
Case1: Oil flow on each grid (AOA=13)

- Sensitivity to the grid density about Flap-TE and Flap-SOB flow separation is small.
- Difference of converged CL and CM mainly seems to depend on the size of Flap TE flow separation

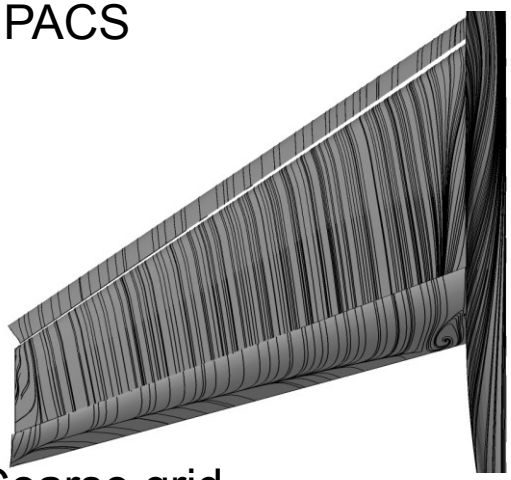
TAS

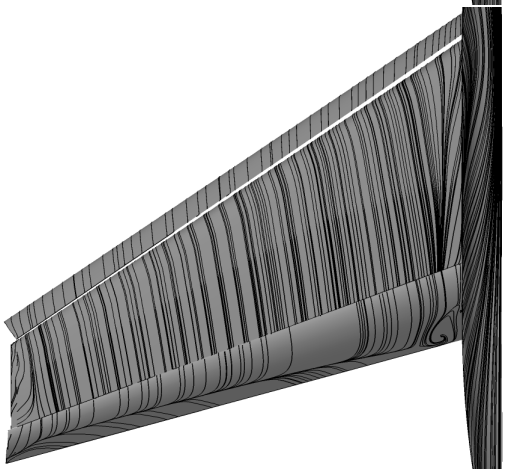


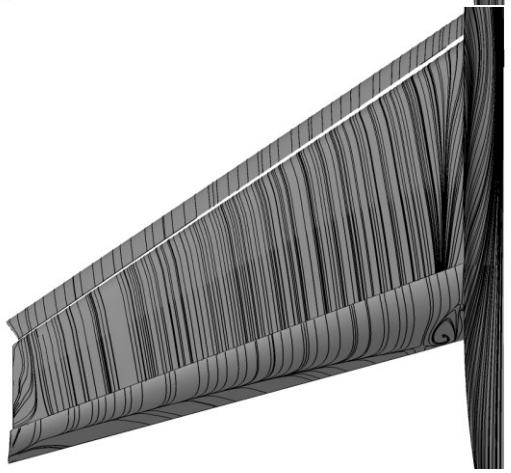




UPACS







Coarse grid

Medium grid

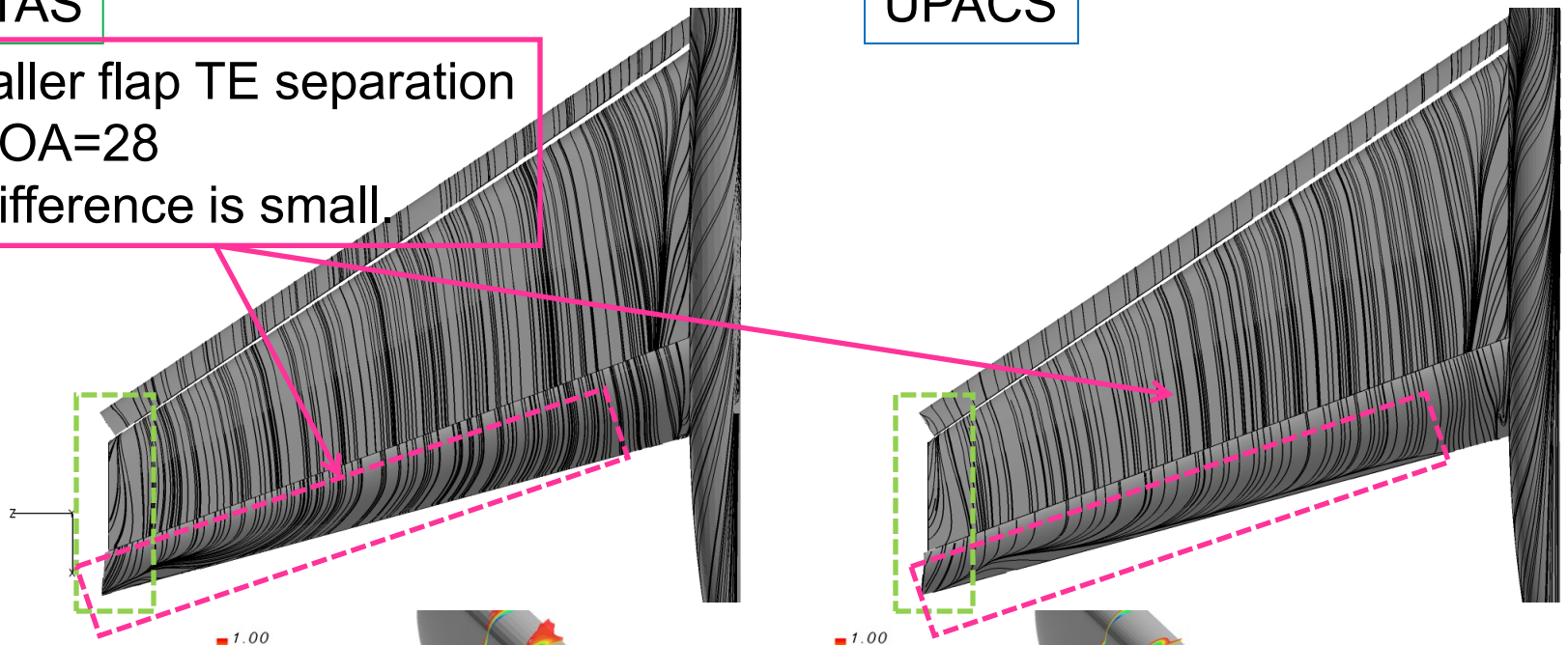
Fine grid

Case1:Oil flow and Ptotal (AOA=28, Medium)

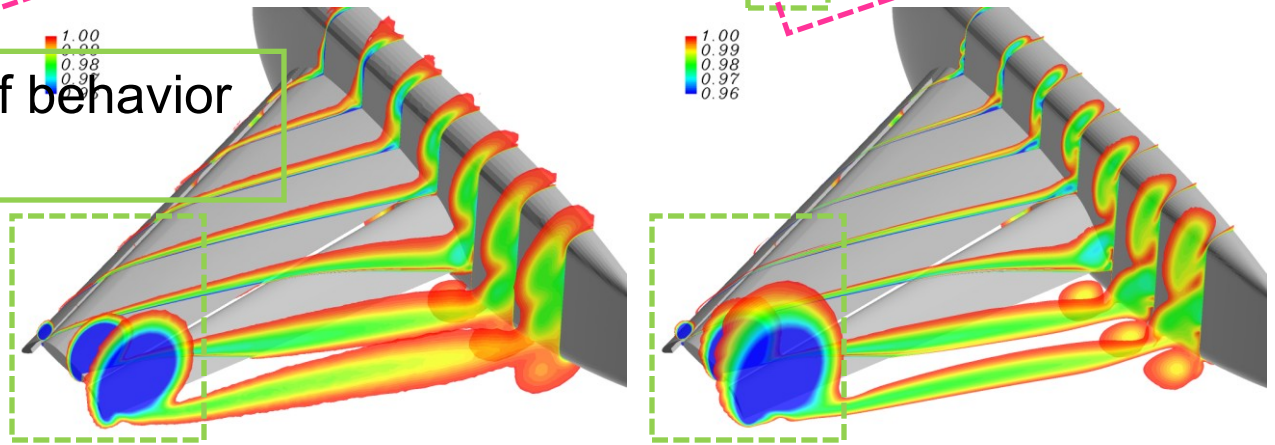
TAS

UPACS

Smaller flap TE separation
at AOA=28
→Difference is small.



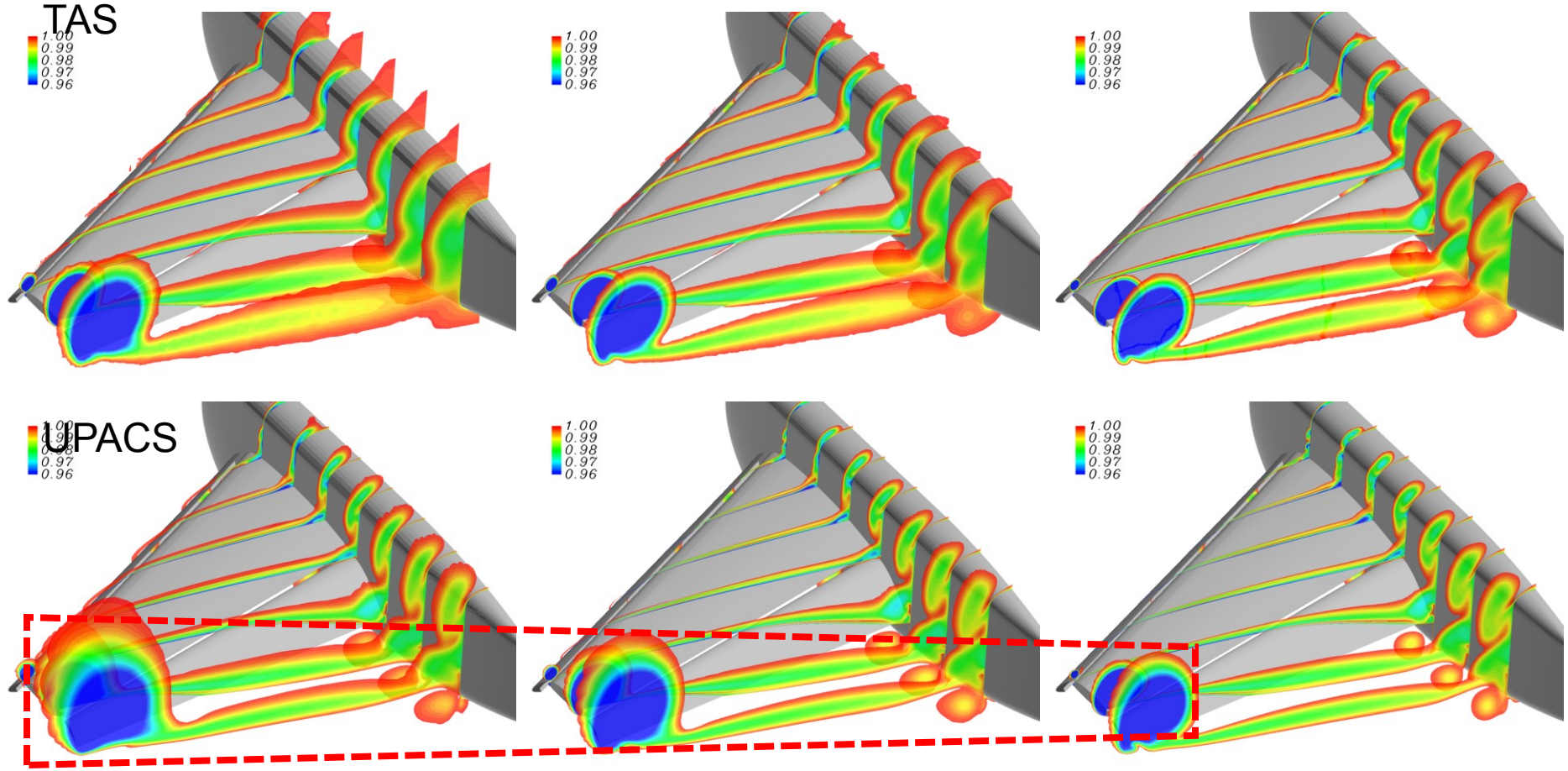
Difference of behavior
of tip vortex



Oilflow and Ptotal at α=28deg by Medium grid (Left:TAS, Right:UPACS)

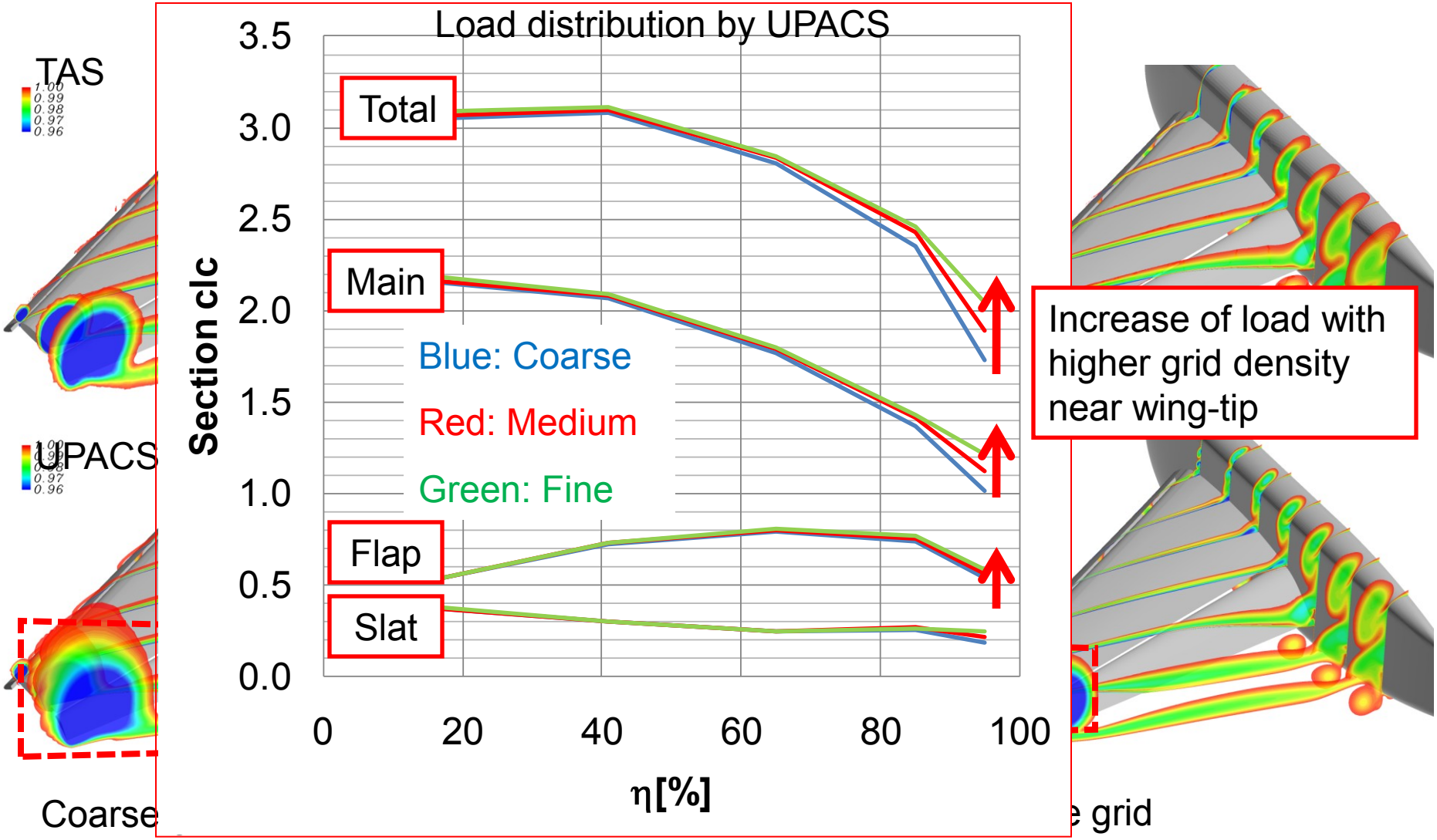
Case1: P_{total} on each grid (AOA=28)

- Sensitivity to the grid density about tip vortex behavior is large especially by UPACS.
  - Larger Pt loss results in Lower CL and Higher CM.



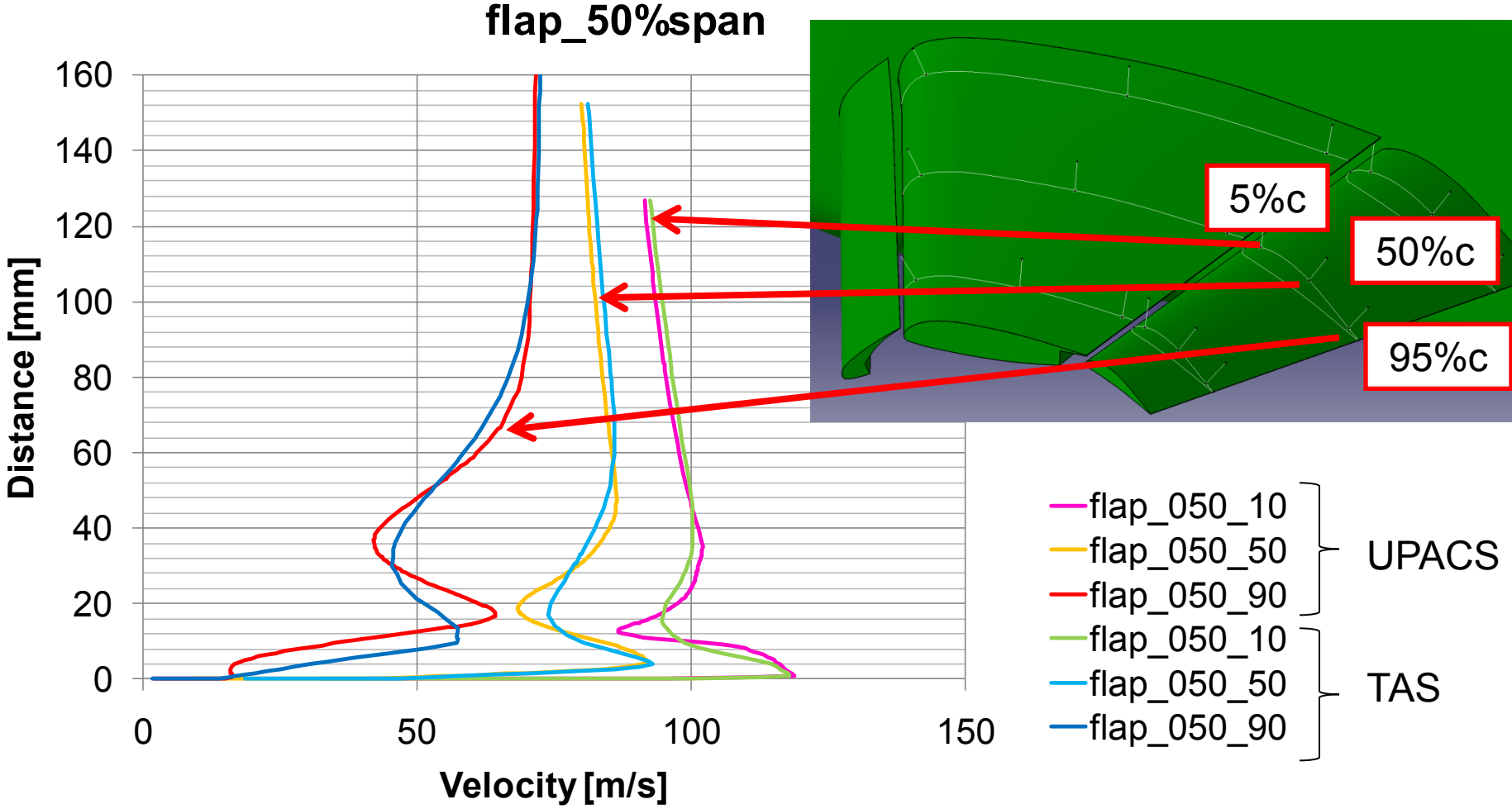
Case1: Pt by each grid (AOA=28)

- Sensitivity to the grid density about tip vortex behavior is large especially by UPACS.



Case1: Boundary layer profile (AOA=13, Medium)

- Sharper wake resolution by UPACS
- How much slat and flap wake resolution is required in 3D high-lift computation?



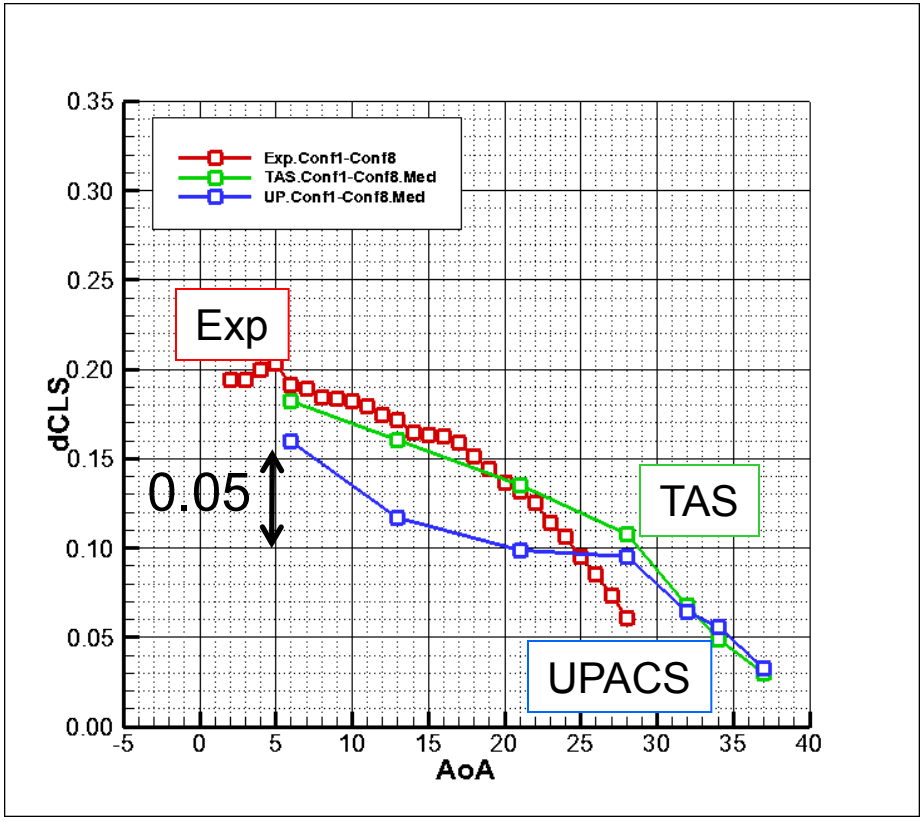
Observations in Case1

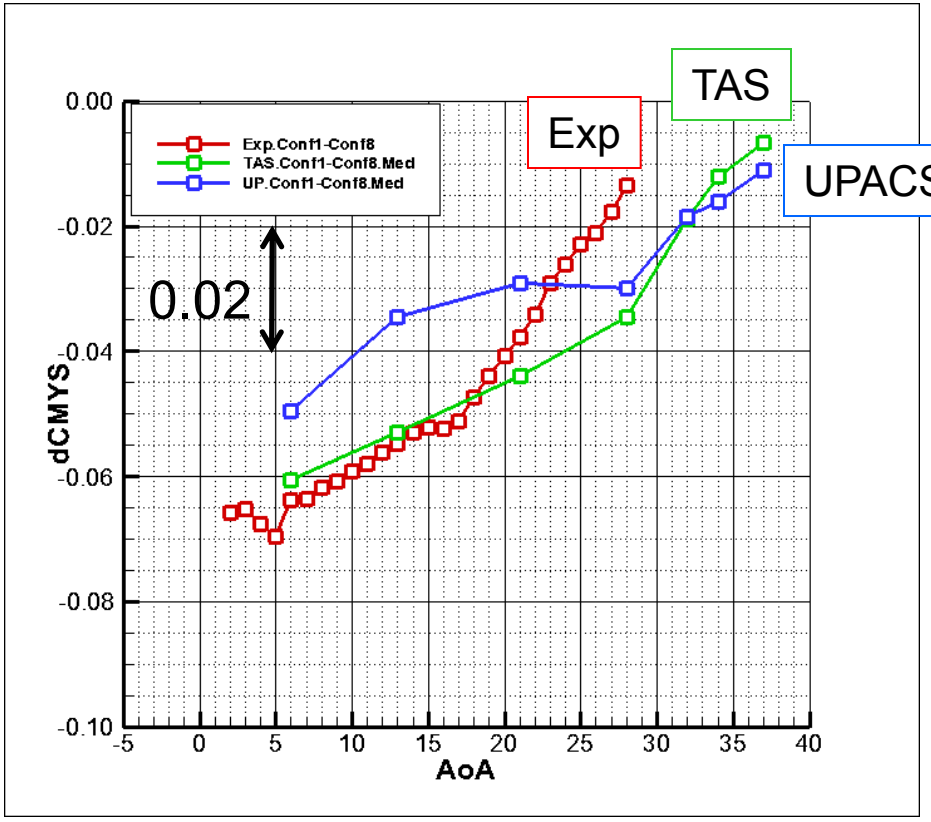
- AOA=13
  - Importance of prediction of Flap TE flow separation
- AOA=28
  - Importance of prediction of tip vortex behavior although the difference will reduce using finer grids

- Case 1 Grid Convergence Study
- Case 2 Flap Deflection Prediction Study
- Case 3 Flap and Slat Support Effects Study

Case2: Delta CL and CM (Config1-Config8)

- Effectiveness of flap deflection by UPACS is under-estimated at a range from 5deg to 20deg
  - Config.8: less difference between UPACS and TAS (not shown here)
    - Smaller flap TE separation and tip vortex due to lower flap deflection
  - Due to larger flap TE flow separation in the case of Config.1.
- At AOA=28, both CFD results over-estimated the effectiveness than that of Exp.





Observations in Case2

- Config.8 shows smaller Flap TE separation and tip vortex due to lower flap deflection.

→ Less sensitivity to the code and grid density

- Both CFD codes show fair agreement with experimental effectiveness of flap deflection except for high AOA.

- Prediction accuracy of effectiveness of flap deflection angle is based on the prediction accuracy of Config.1, where the flow separation becomes larger.

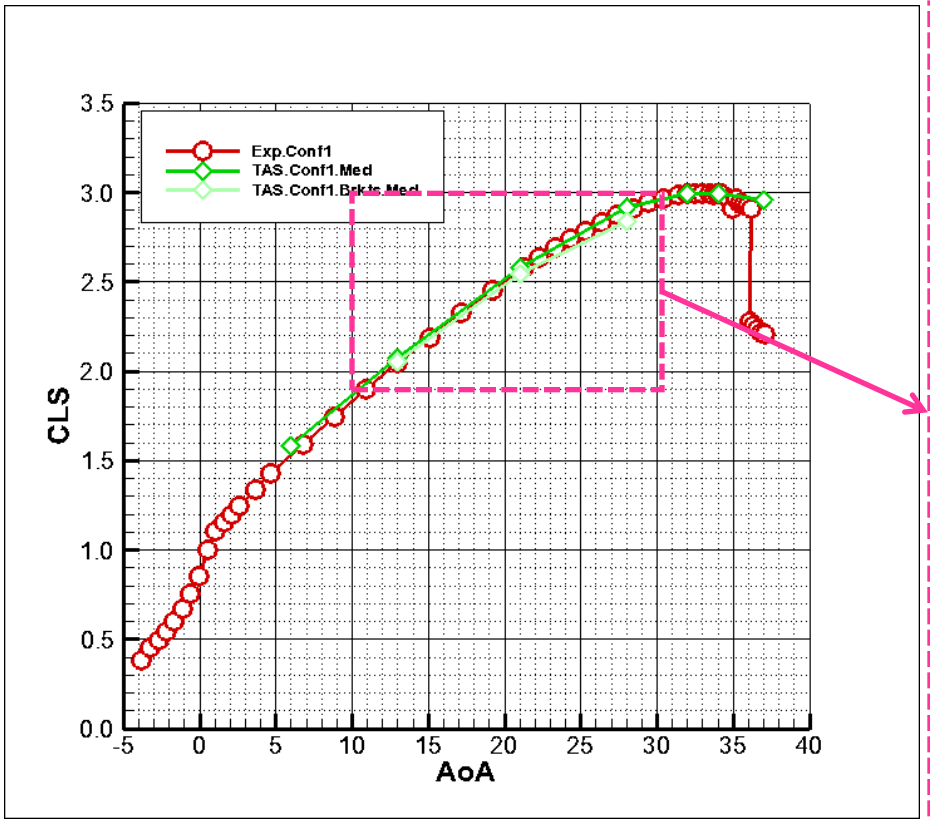
- Case 1 Grid convergence Study
- Case 2 Flap Deflection Prediction Study
- Case 3 Flap and Slat Support Effects Study

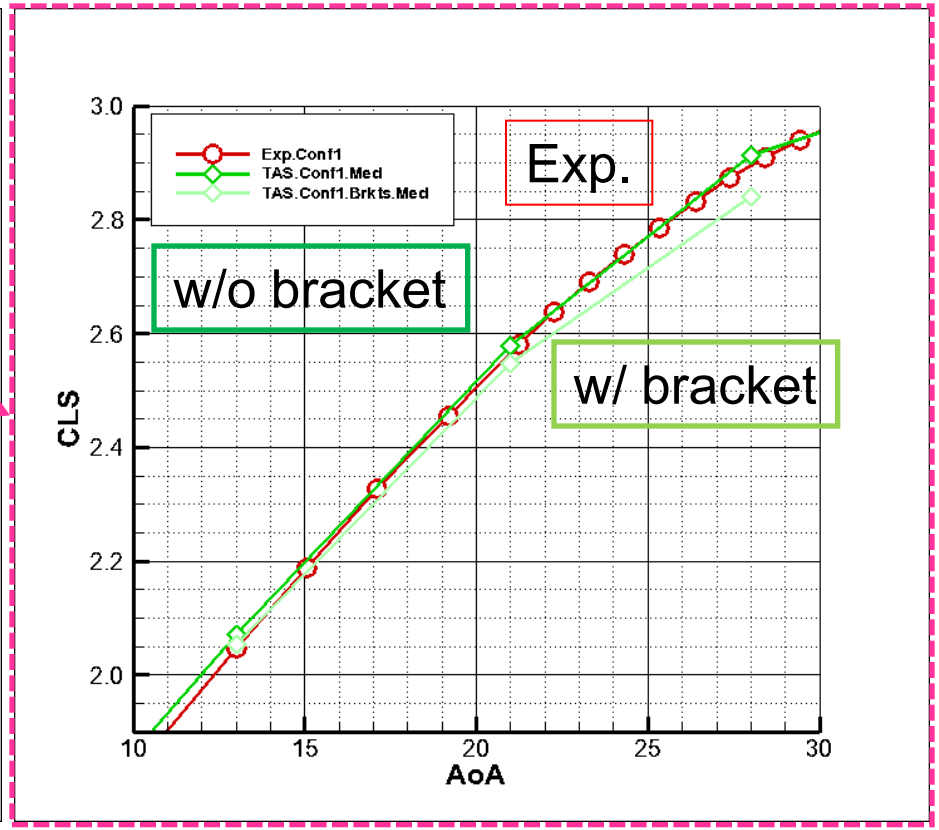
Case3:CL-alpha

Δ = (w/ bracket) – (w/o bracket)

AOA	ΔCL
13	−0.018
21	−0.033
28	−0.072

Larger decrease by bracket at AOA=28 than at AOA=13

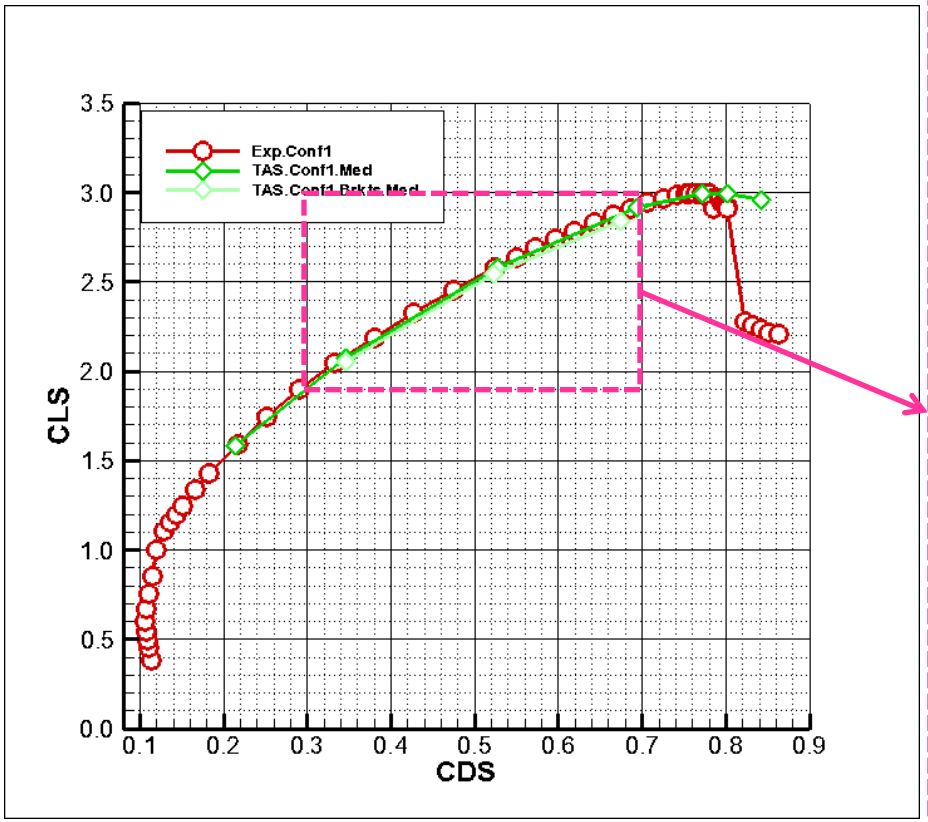


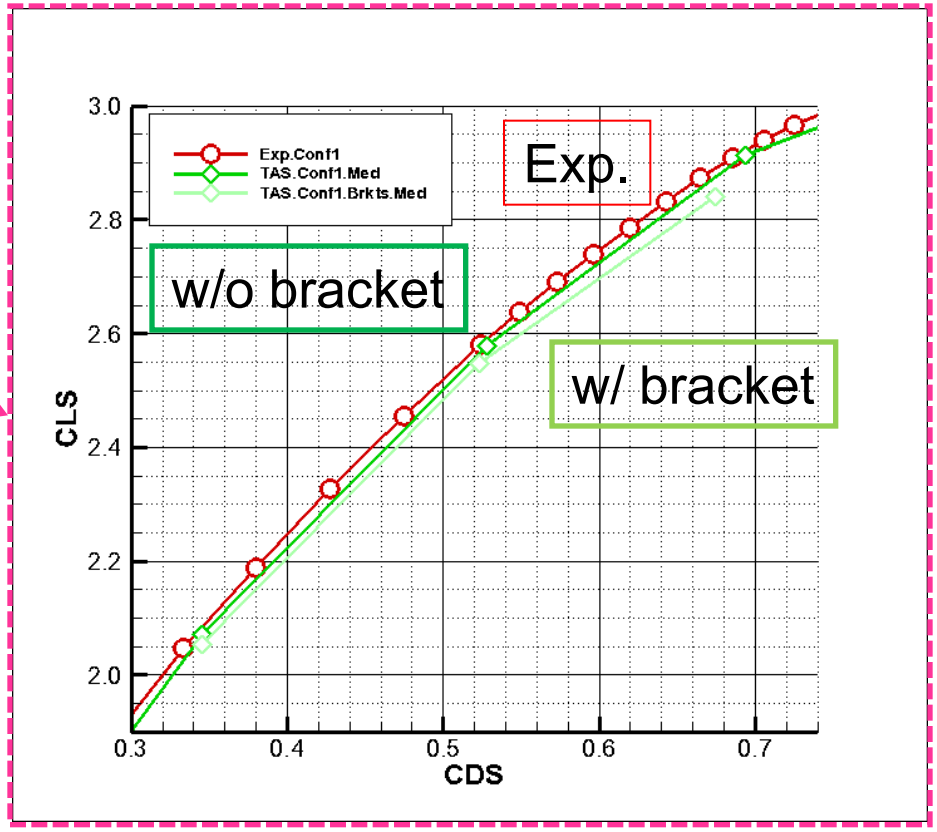


Case3:CL-CD

Δ = (w/ bracket) – (w/o bracket)

AOA	ΔCD	Δ(CD-CDi)
13	-0.0003	0.0023
21	-0.0047	0.0011
28	-0.0198	-0.0053



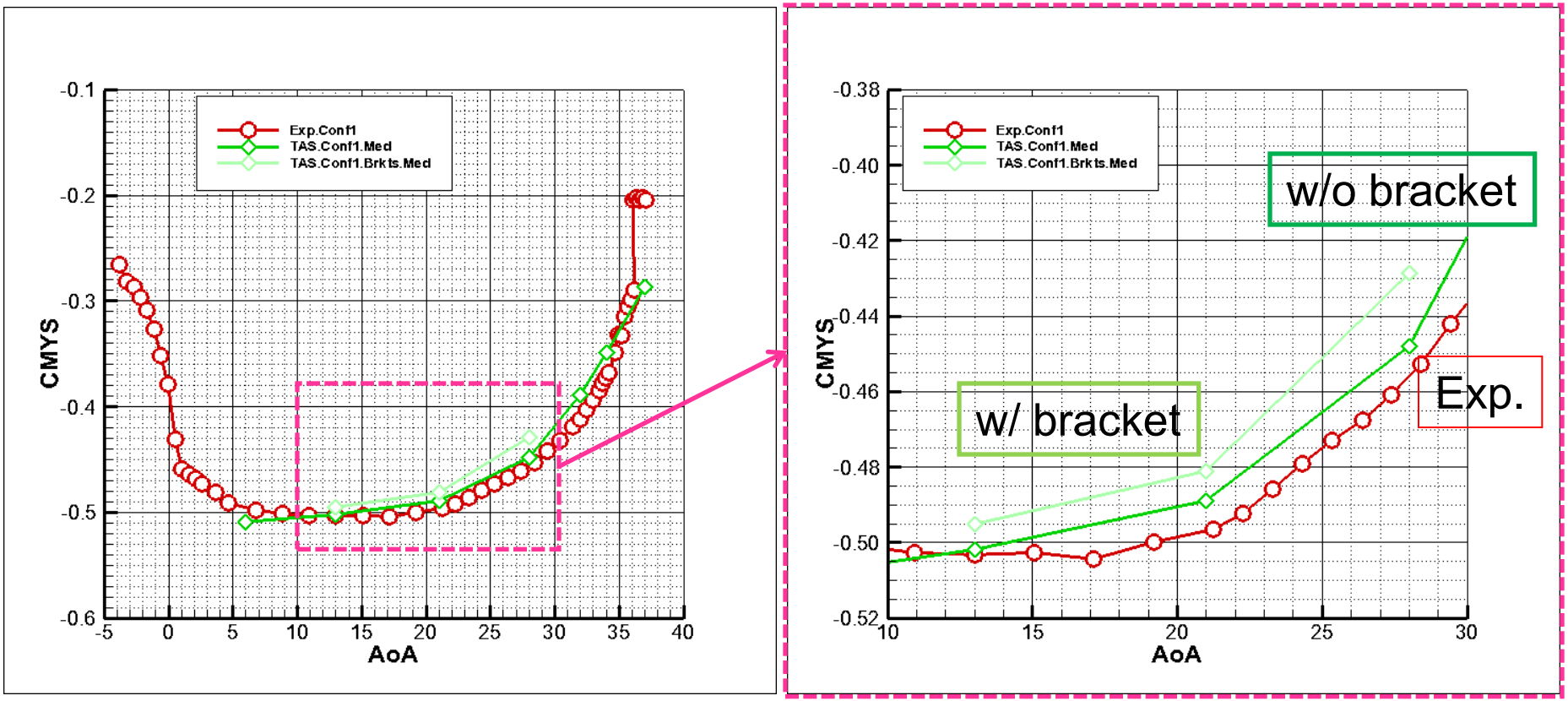


Case3:CM-alpha

Δ = (w/ bracket) – (w/o bracket)

AOA	ΔCM
13	−0.0065
21	−0.0078
28	−0.0193

Larger change by bracket at AOA=28 than at AOA=13

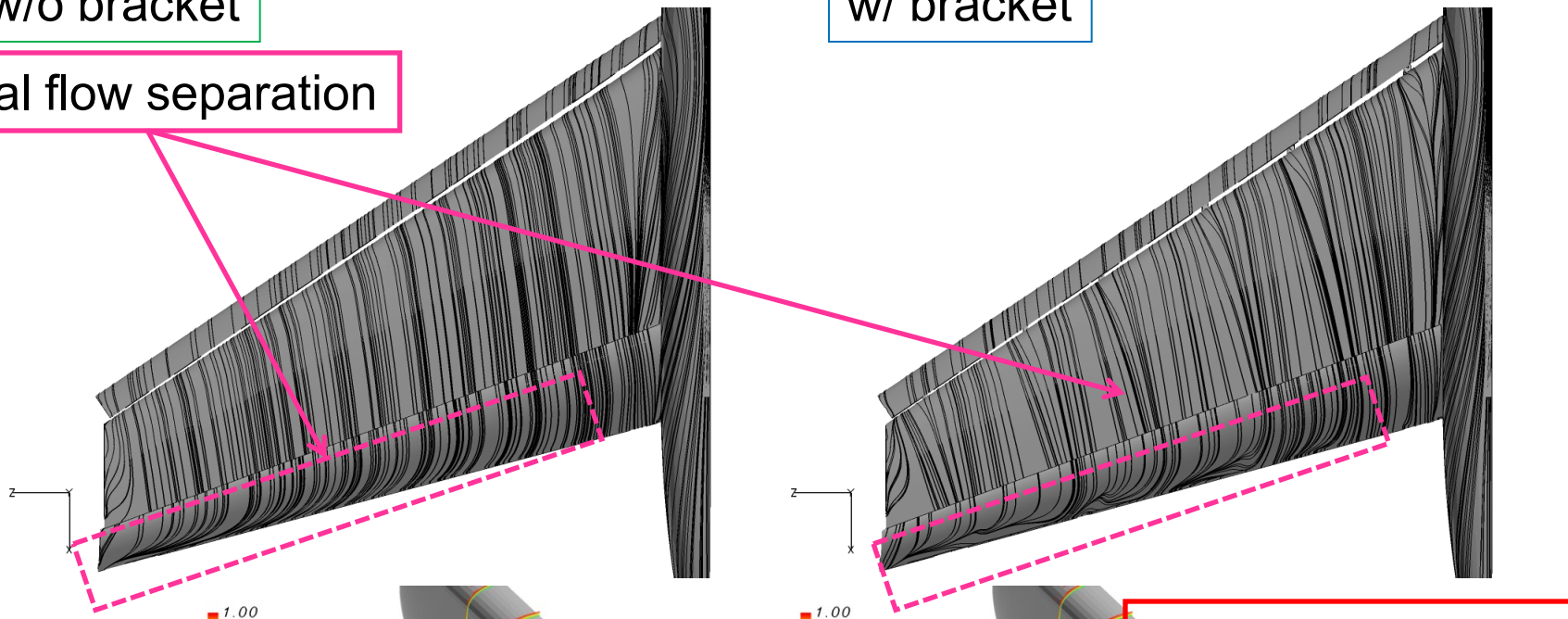


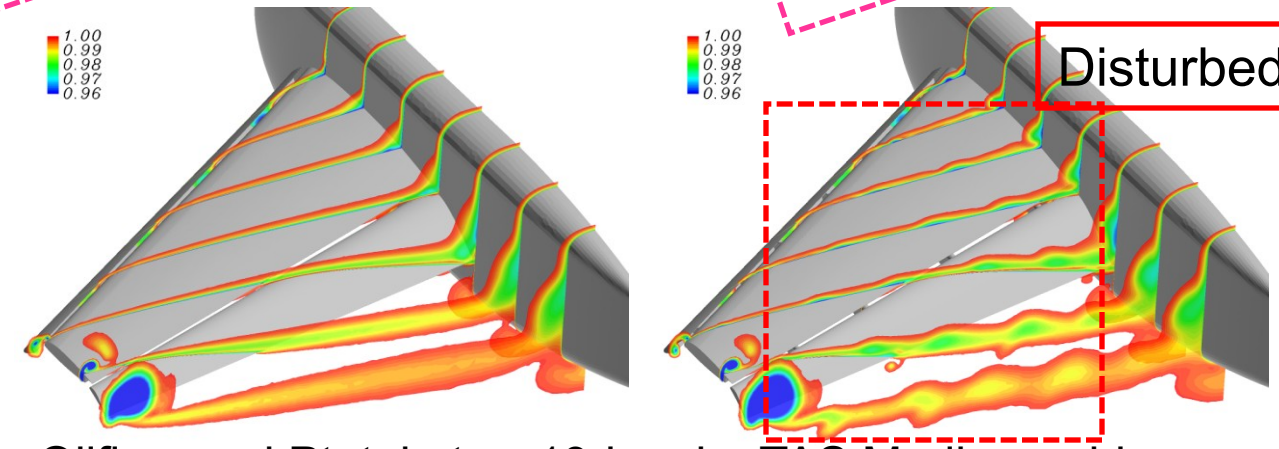
Case3:Oil flow and Ptotal (AOA=13, Medium)

w/o bracket

w/ bracket

Local flow separation





Disturbed wake flow

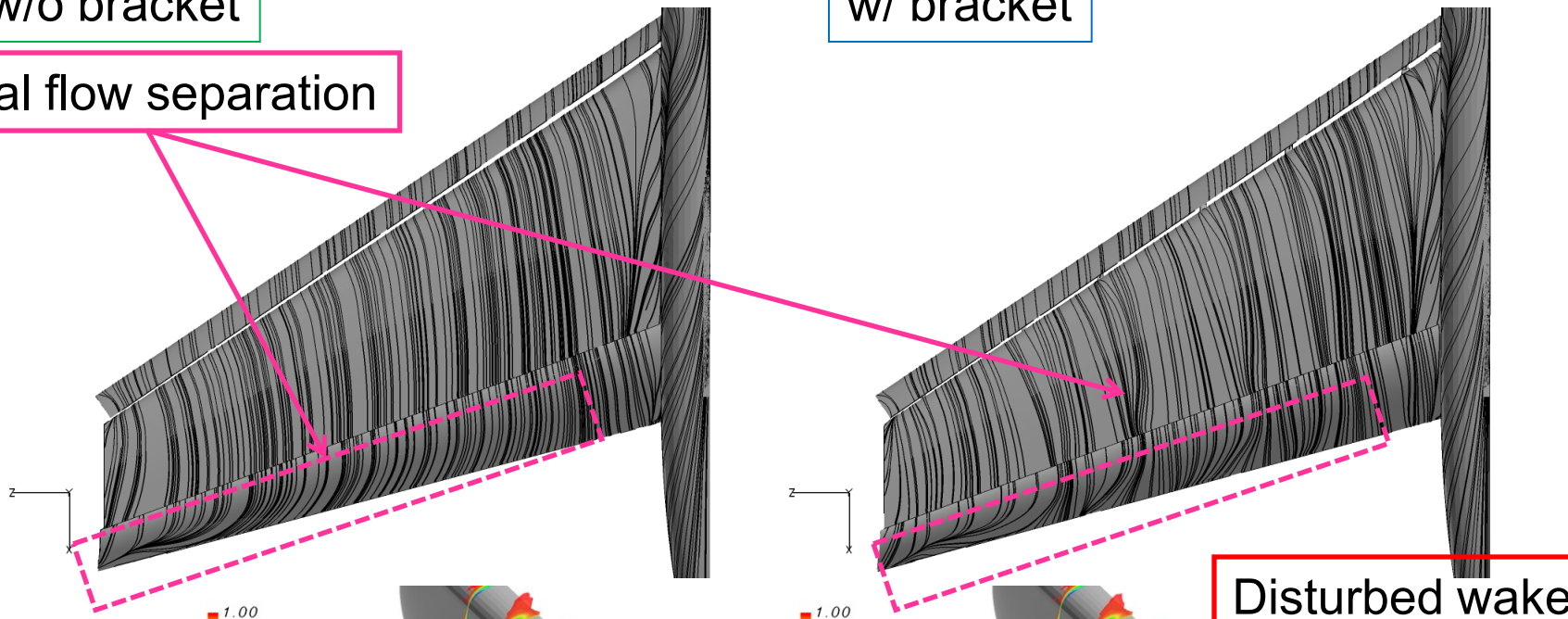
Oilflow and Ptotal at α=13deg by TAS Medium grid

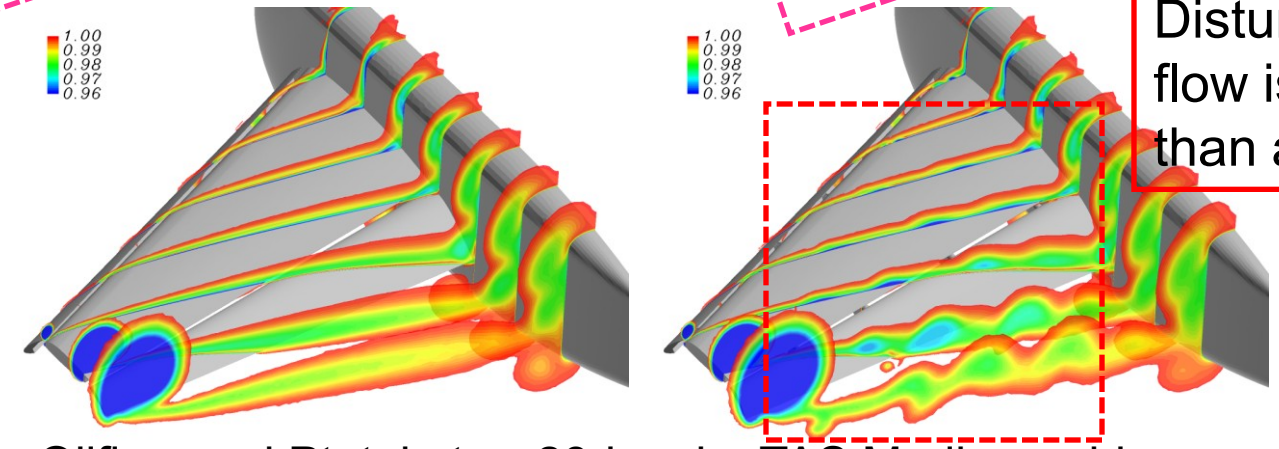
Case3:Oil flow and Ptotal (AOA=28, Medium)

w/o bracket

w/ bracket

Local flow separation





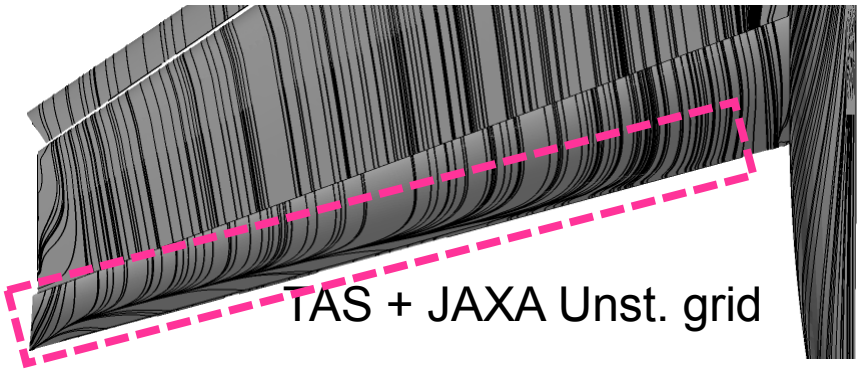
Disturbed wake flow is larger than at AOA=13

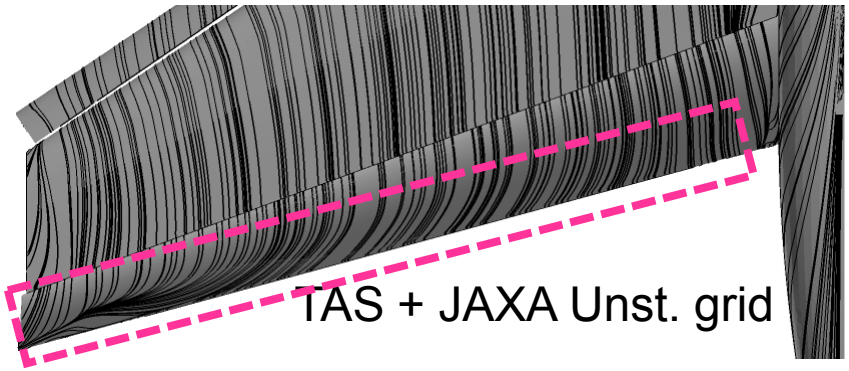
Oilflow and Ptotal at α=28deg by TAS Medium grid

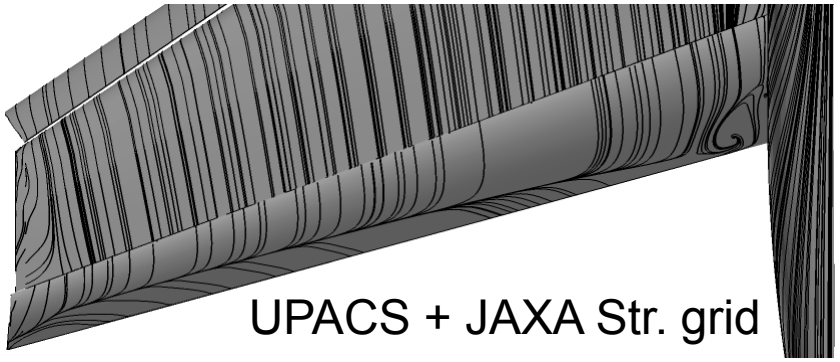
- Additional evaluations
  - Comparison of unstructured grid generation method
    - JAXA Self-generated and Wyoming grids by TAS
    - Change of local grid densities on the flap trailing-edge
  - Comparison of turbulence model
    - Spalart-Allmaras model and Menter's SST model by TAS
    - Influence of modeling in Spalart-Allmaras model

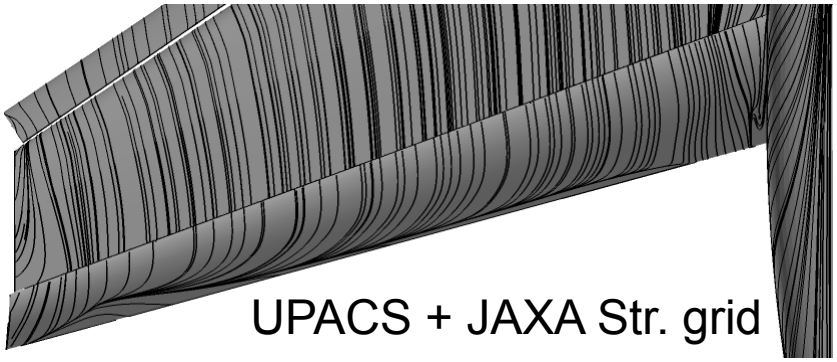
- Additional evaluations
  - Comparison of unstructured grid generation method
    - JAXA Self-generated and Wyoming grids by TAS
    - Change of local grid densities on the flap trailing-edge
  - Comparison of turbulence model
    - Spalart-Allmaras model and Menter's SST model by TAS
    - Influence of modeling in Spalart-Allmaras model by UPACS

Comparison of unstructured grid generation method

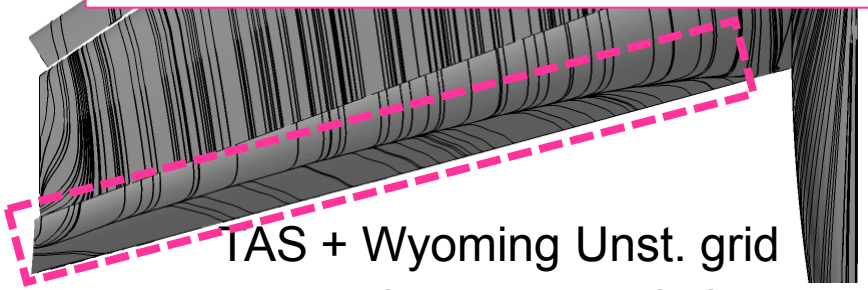








Larger Flap TE separation →Lift decrease and pitch-up(comparable to UPACS)



AOA=13 Oilflow on Medium grid AOA=28

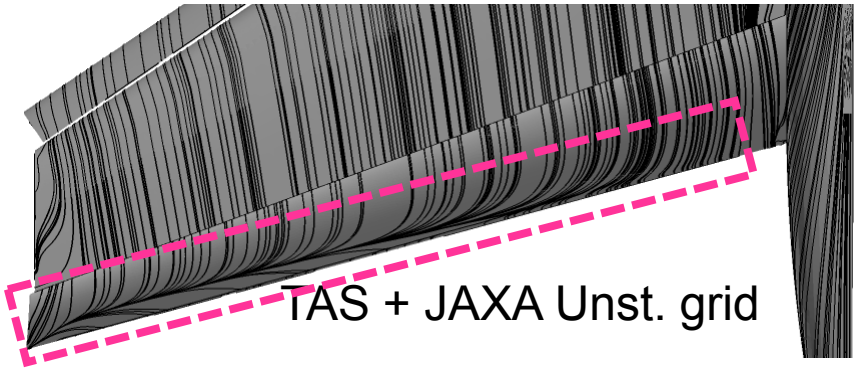
Comparison of unstructured grid generation method

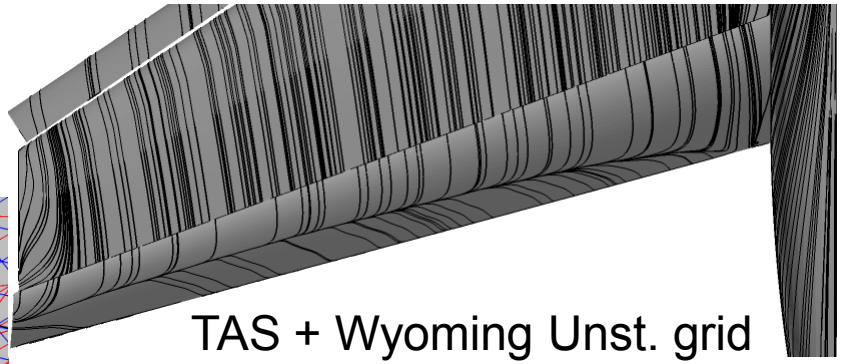
- Difference of Flap TE flow separation
  - What is different between JAXA and Wyoming Unstructured grid (and JAXA Structured grid)?
    - (1) Grid points on each blunt trailing-edge?
      - JAXA unstructured grids have only one cell on each TE
    - (2) Influence of anisotropic surface triangulation?
      - JAXA unstructured grids use nearly-isotropic surface triangulation.

Comparison of unstructured grid generation method

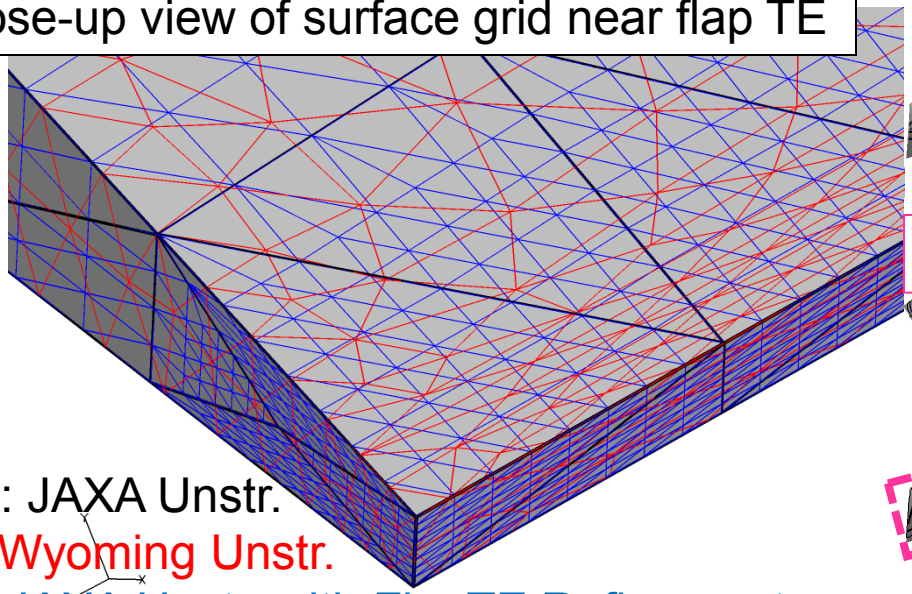
- (1) Grid points on each blunt trailing-edge?
  - Check(1): Local grid refinement ONLY on Flap TE

→ Larger Flap TE flow separation!

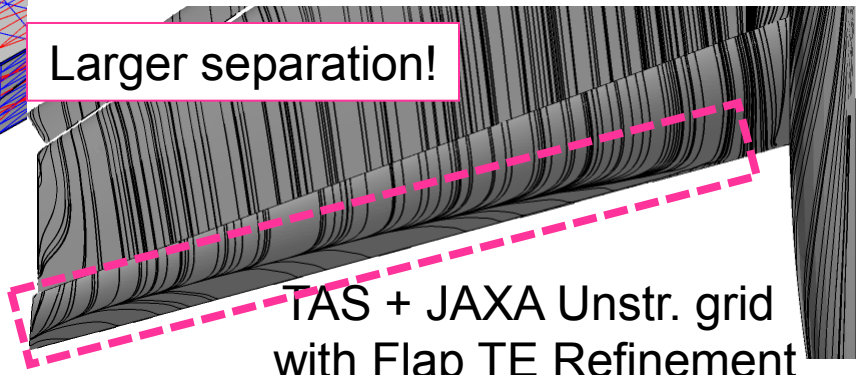




Close-up view of surface grid near flap TE



Larger separation!



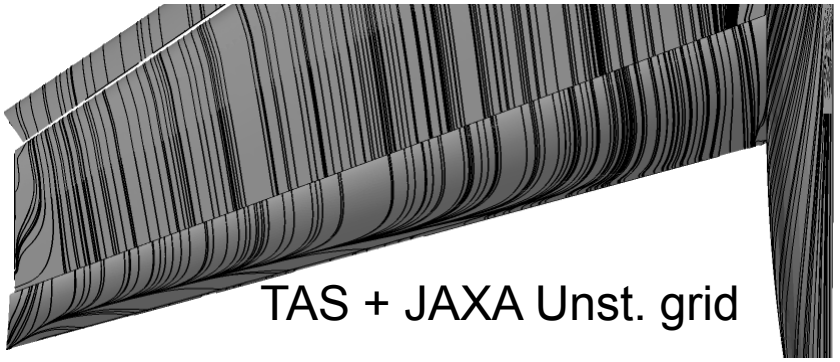
Black: JAXA Unstr.
Red: Wyoming Unstr.
Blue: JAXA Unstr. with FlapTE Refinement

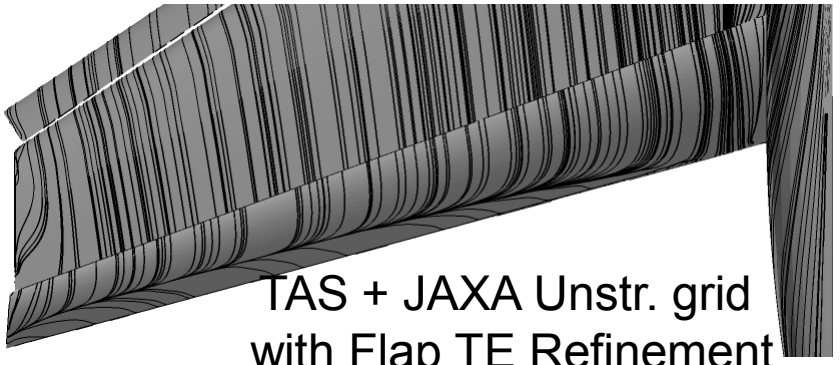
AOA=13

Comparison of unstructured grid generation method

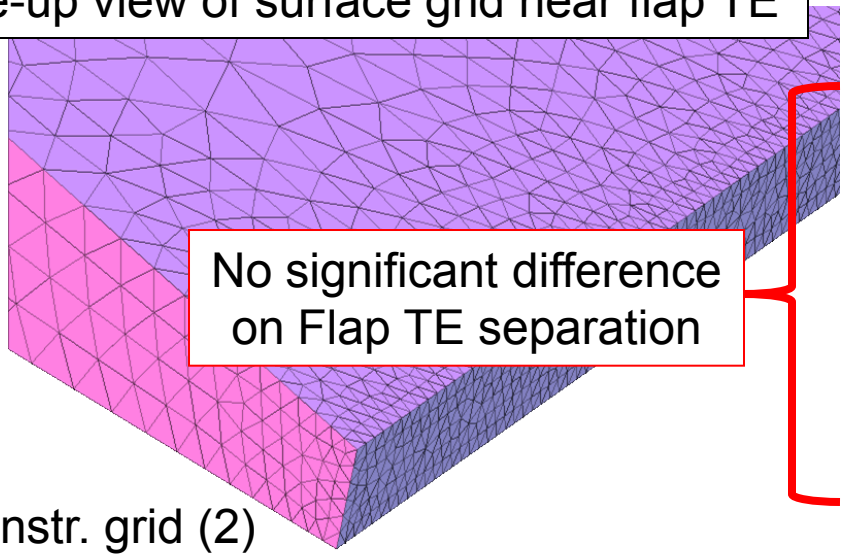
- (2) Influence of anisotropic surface triangulation?
  - Check(2):Insertion of isotopic triangles on Flap TE (Mesh points considerably increase!)

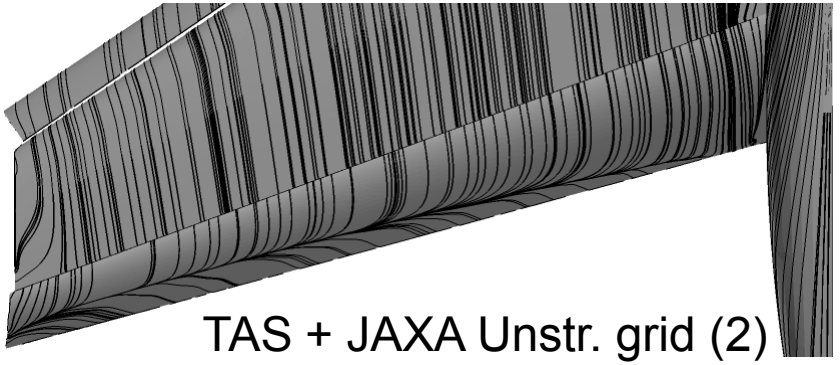
→ Larger Flap TE flow separation
Not due to anisotropic triangles





Close-up view of surface grid near flap TE





JAXA Unstr. grid (2)
Other gridding parameters are identical to coarse grid

AOA=13

- Additional evaluations
  - Comparison of unstructured grid generation method
    - JAXA Self-generated and Wyoming grids by TAS
    - Change of local grid densities on the flap trailing-edge
  - Comparison of turbulence model
    - Spalart-Allmaras model and Menter's SST model by TAS
    - Influence of modeling in Spalart-Allmaras model by UPACS

SA model in TAS and UPACS: SAmod

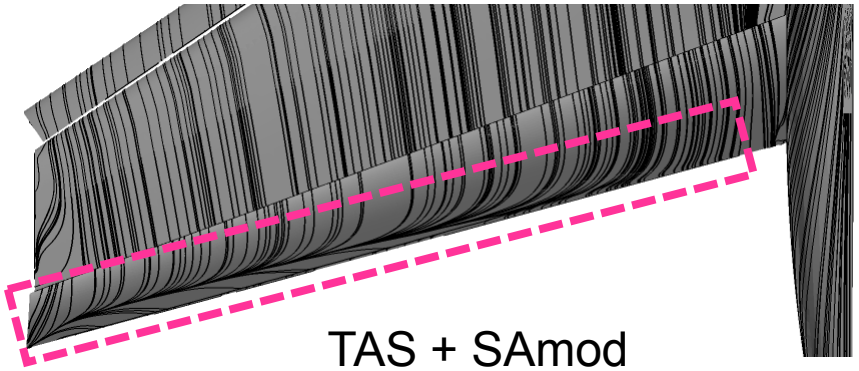
$$S = \min(\sqrt{2\Omega}, \sqrt{2S^2})$$

SA model using vorticity: SAvort

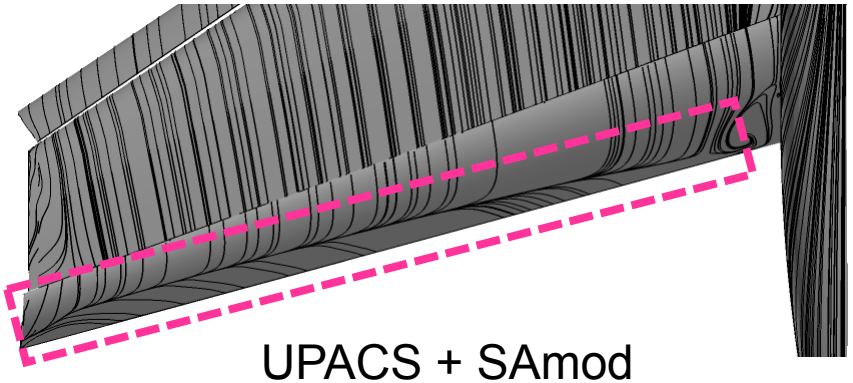
$$S = \sqrt{2\Omega}$$

Comparison of turbulence model

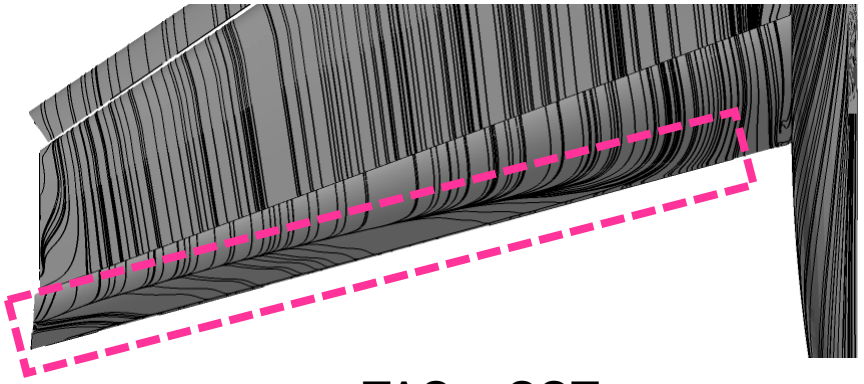
- AOA=13
  - SST model shows larger TE flow separation
  - SAvort shows smaller TE flow separation



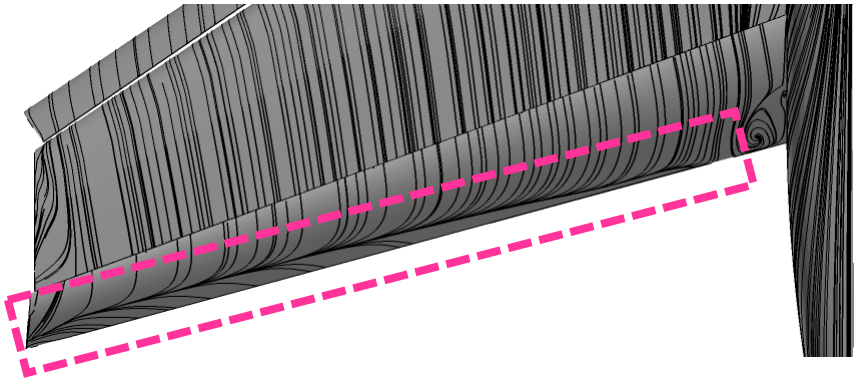
TAS + SAmod



UPACS + SAmod



TAS + SST

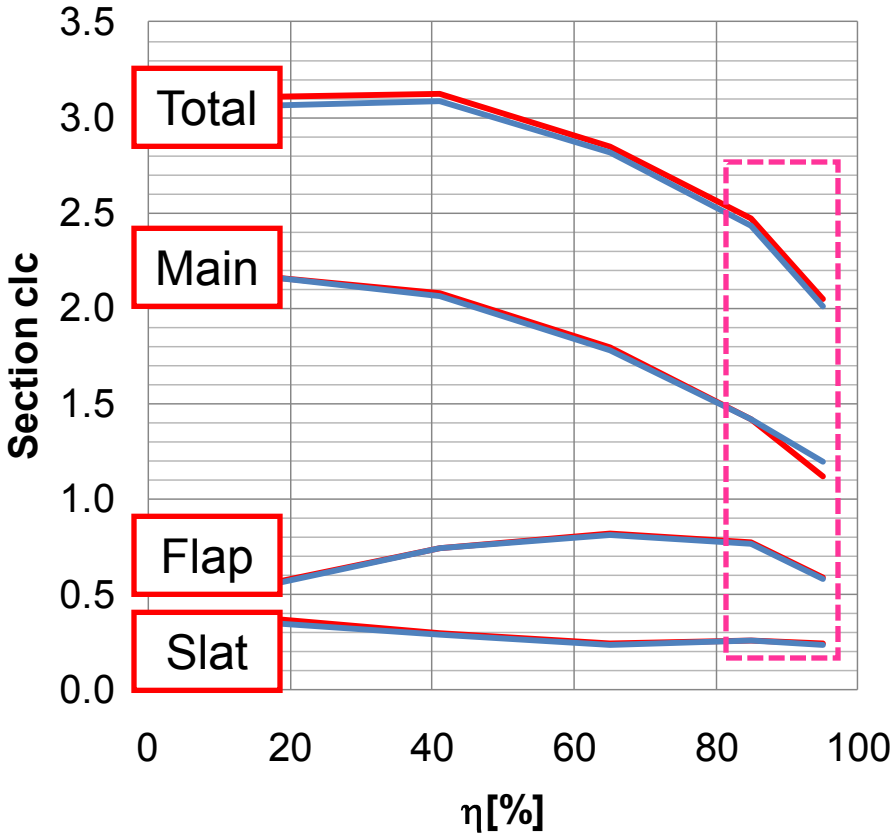


UPACS+SA vort

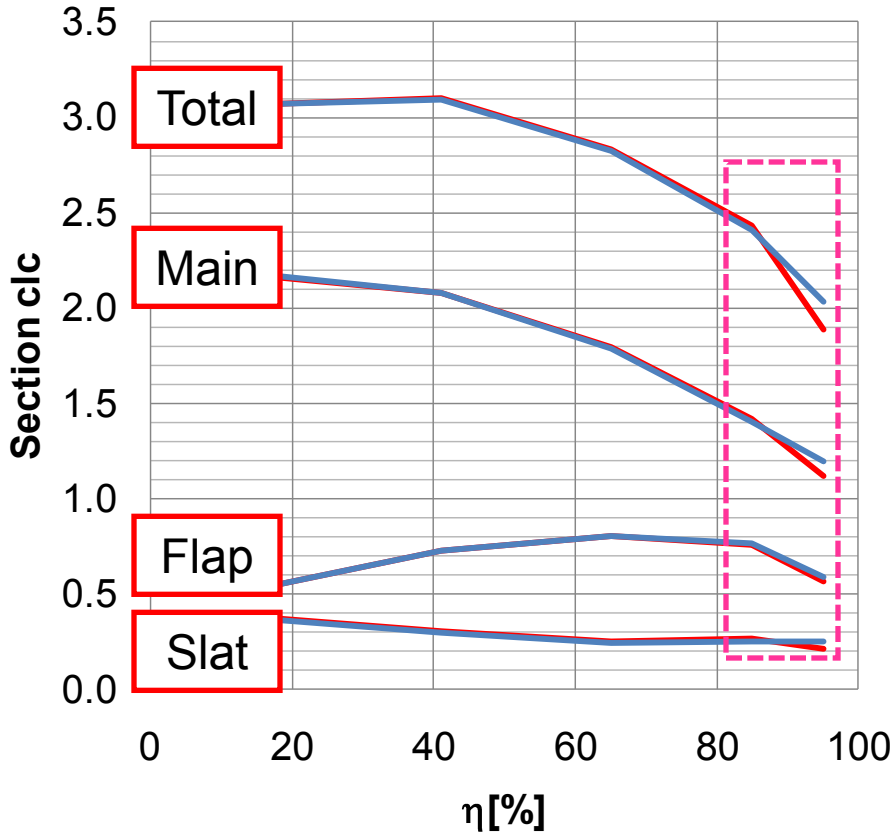
Oilflow on Medium grid (AOA=13)

Comparison of turbulence model

- Span load distribution at AOA=28
  - Influence on tip vortex behavior



Blue: TAS + SAmod
Red: TAS + SST



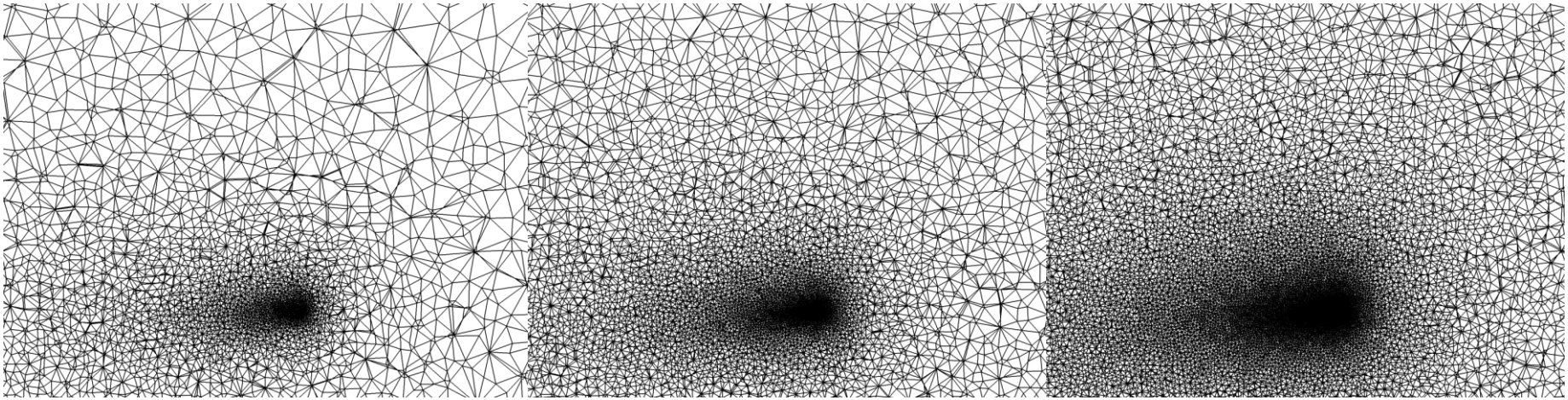
Blue: UPACS + SAmod
Red: UPACS+SA vort

- Thank you for your attention. Any questions?

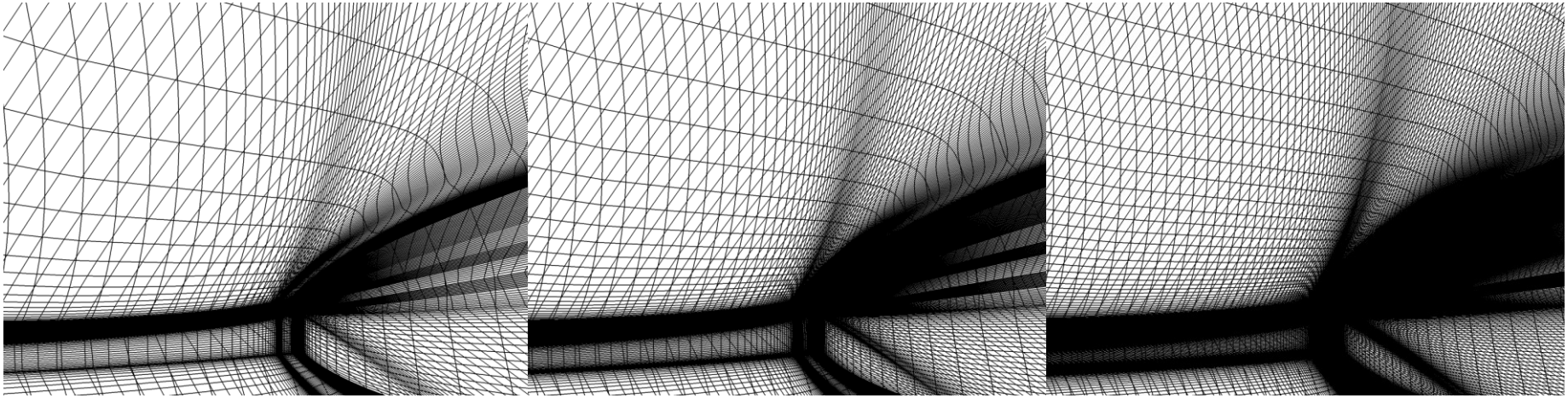
Backup slides

Grid cross-sectional view through flap outer TE

JAXA Unstructured Grid



JAXA Structured Grid



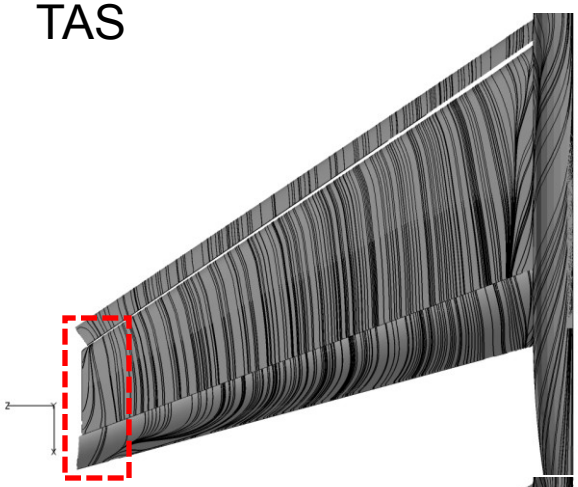
Coarse Medium Fine

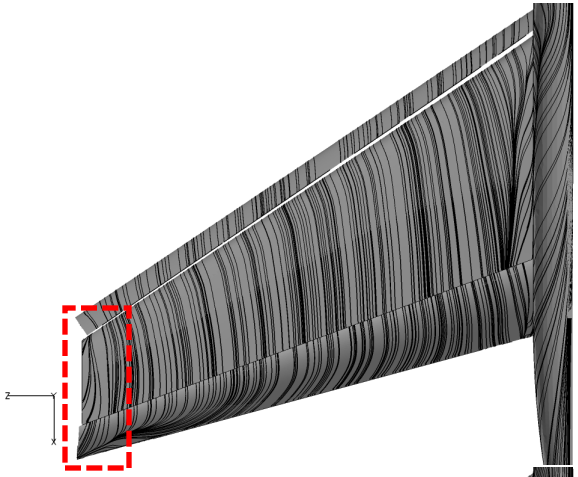
Grid cross-sectional view through flap outer TE

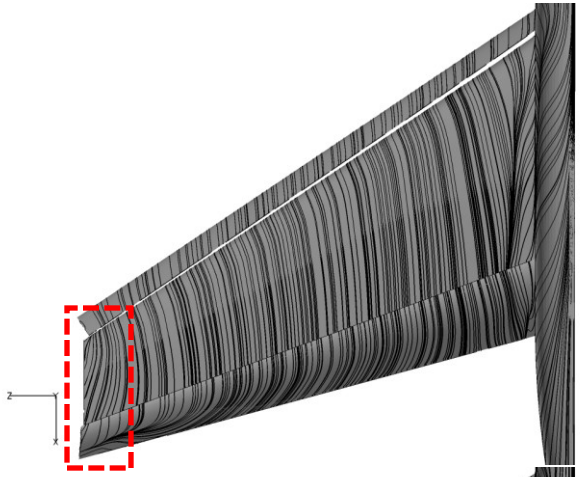
Case1: Oil flow on each grid (AOA=28)

- Less sensitivity to the grid density for Flap-TE flow separation
- Larger sensitivity to the grid density for Wing-tip especially by UPACS

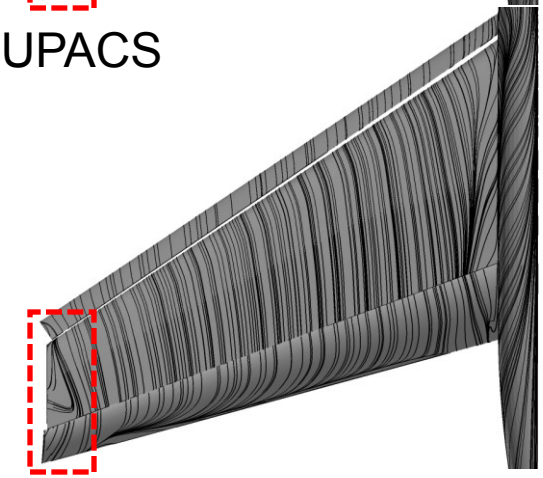
TAS

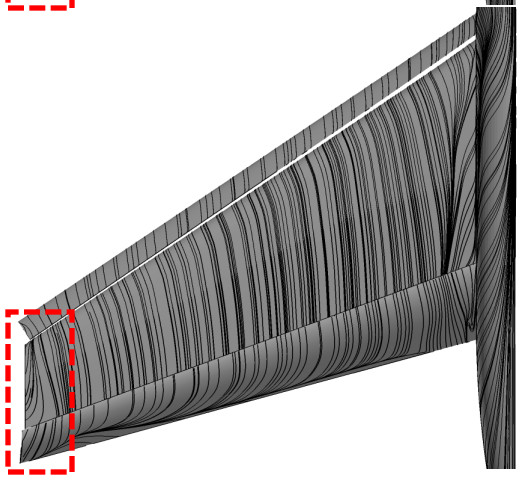


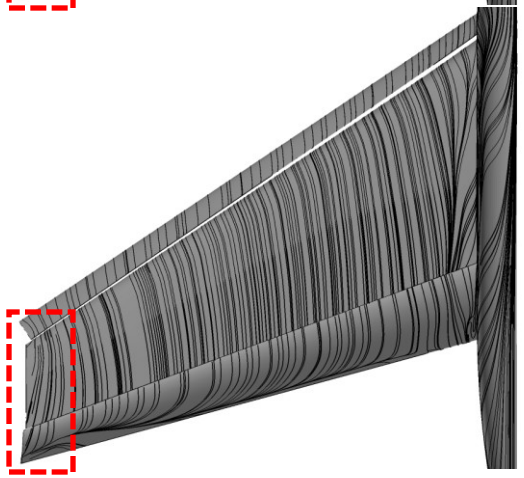




UPACS







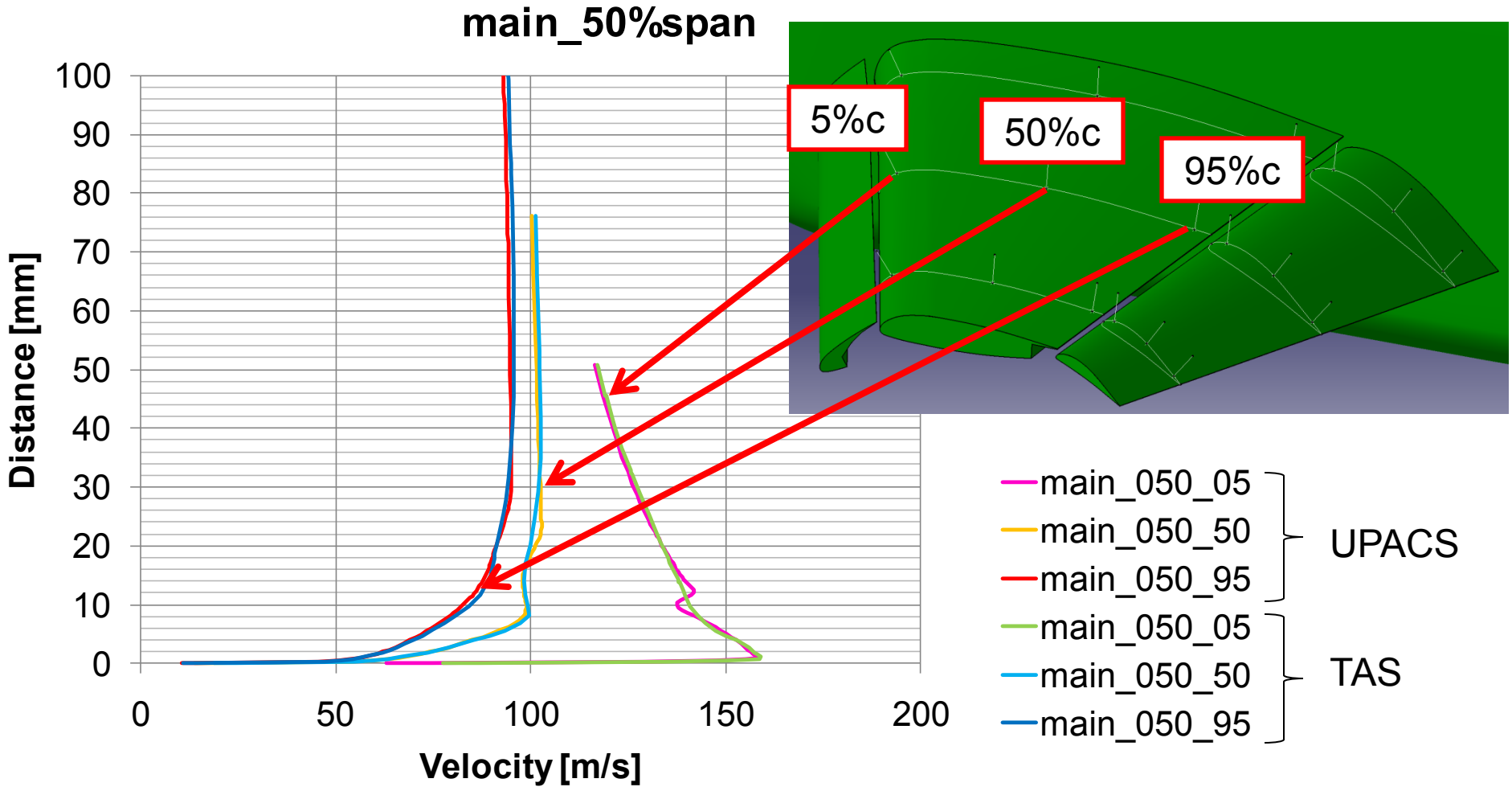
Coarse grid

Medium grid

Fine grid

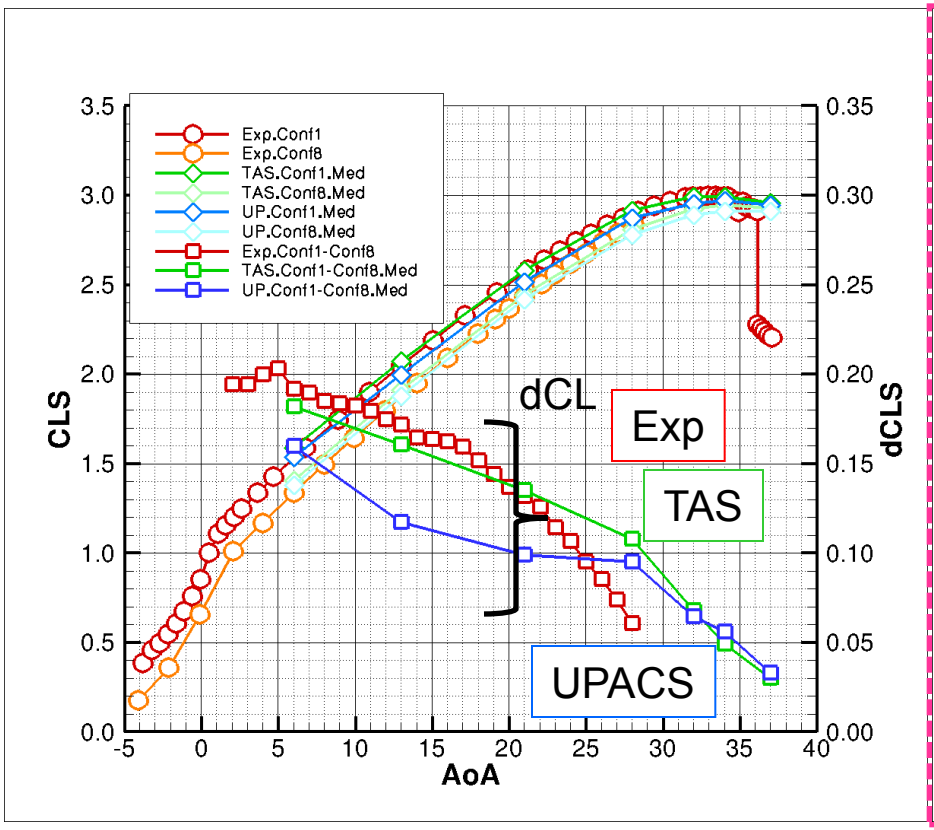
Case1: Boundary layer profile (AOA=13, Medium)

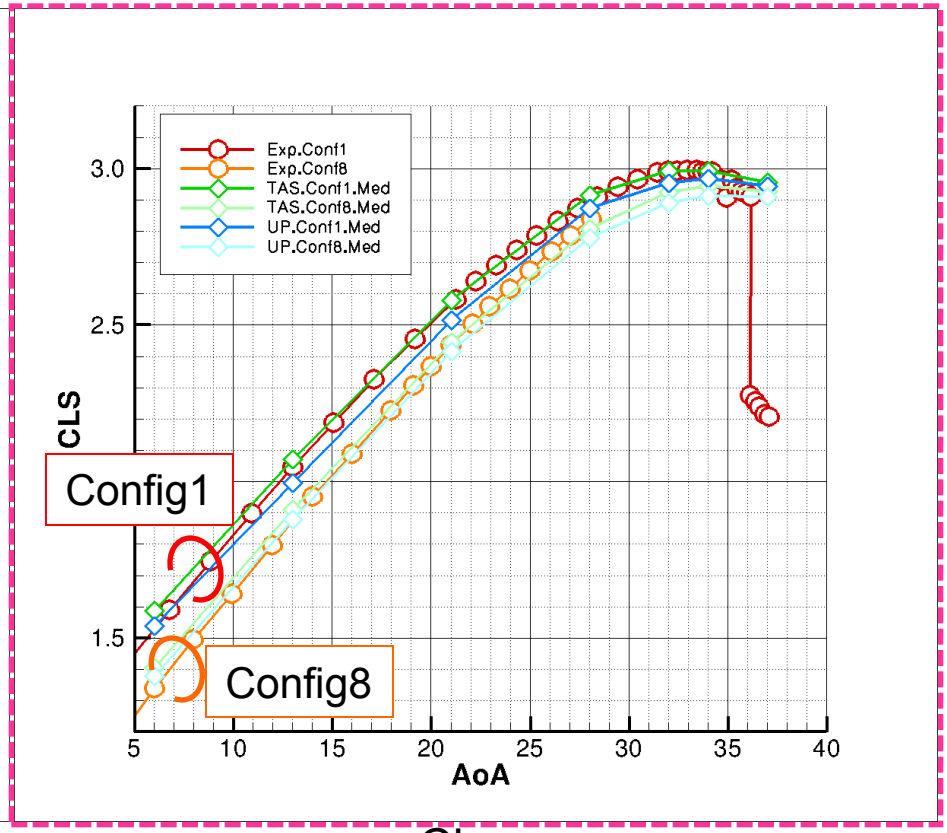
- Sharper wake resolution by UPACS



Case2: CL-alpha

- Less difference between UPACS and TAS at Config8.
  - Smaller flap TE separation and tip vortex due to lower flap deflection
- Fair agreement with experimental effectiveness of flap deflection
- Effectiveness of flap deflection is under-estimated at a range from 5deg to 20deg by UPACS due to lower CL than Exp. by the flap TE flow separation.
- At AOA=28, both CFD results over-estimated the effectiveness than that of Exp.

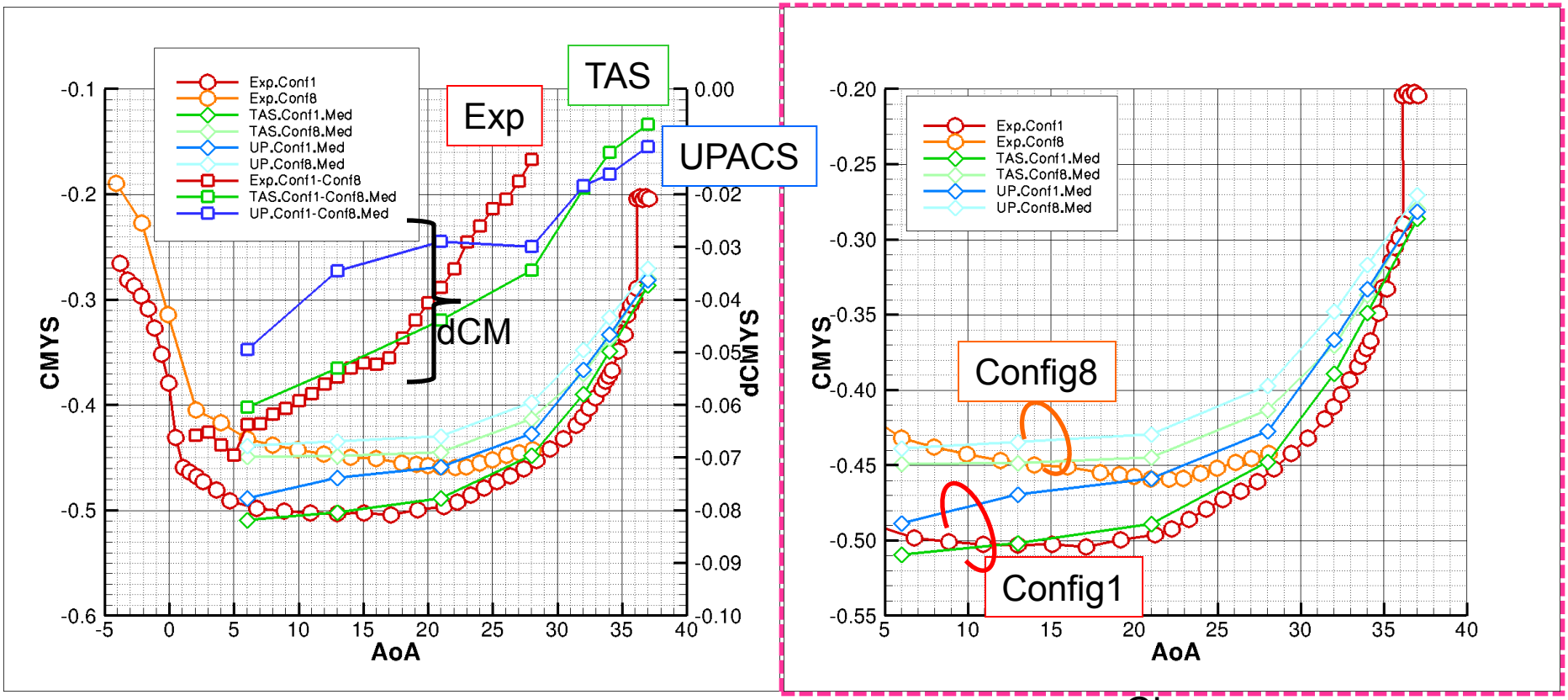




Close-up

Case2: CM-alpha

- Less difference between UPACS and TAS at Config8.
  - Smaller flap TE separation and tip vortex due to lower flap deflection
- Fair agreement with experimental effectiveness of flap deflection
- Change by flap deflection is under-estimated at a range from 5deg to 20deg by UPACS due to lower CL than Exp. by the flap TE flow separation.
- At AOA=28, both CFD results over-estimated the change than that of Exp.



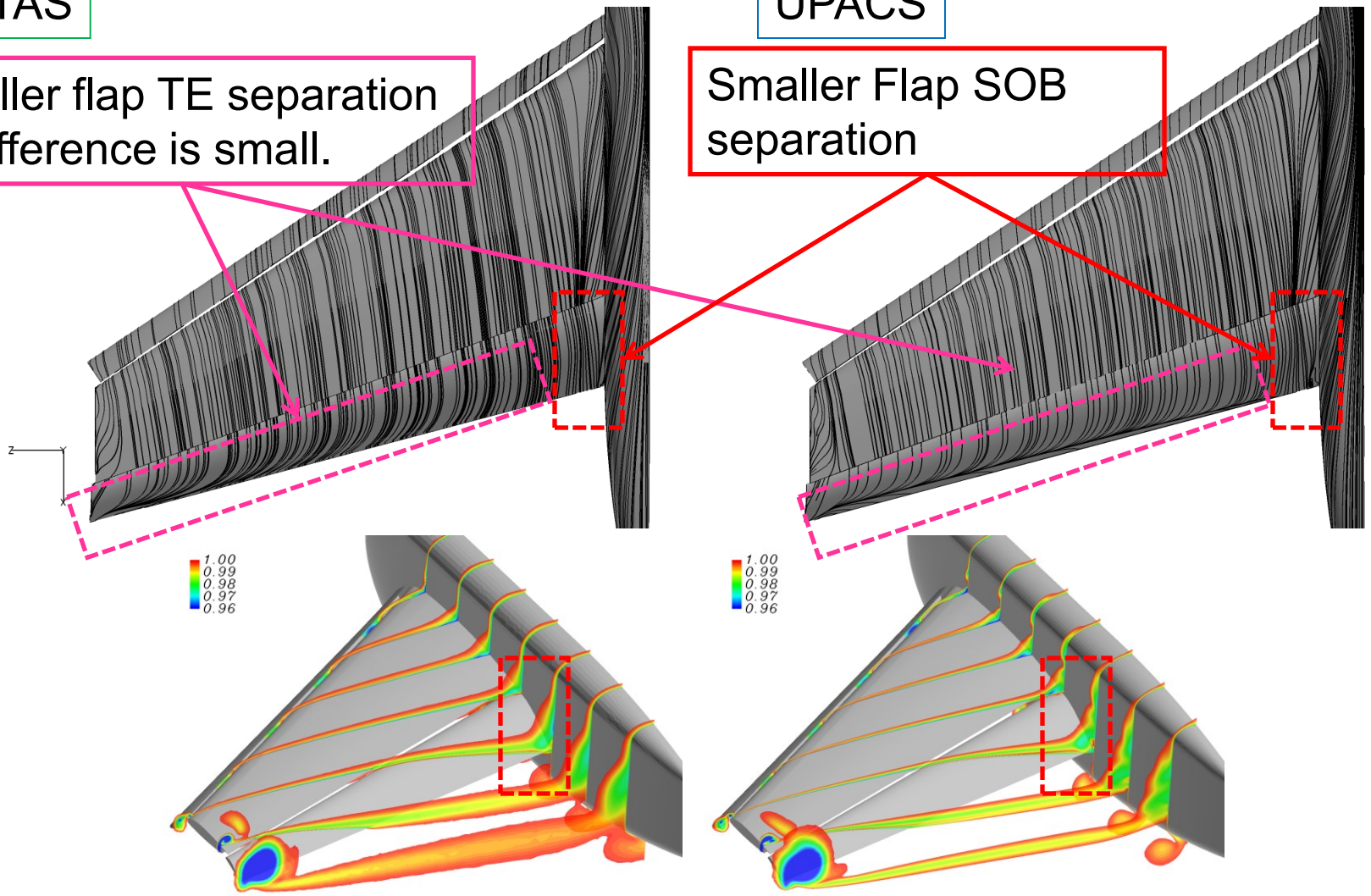
Case2:Oil flow and Ptotal (AOA=13, Medium)

TAS

UPACS

Smaller flap TE separation
→Difference is small.

Smaller Flap SOB separation



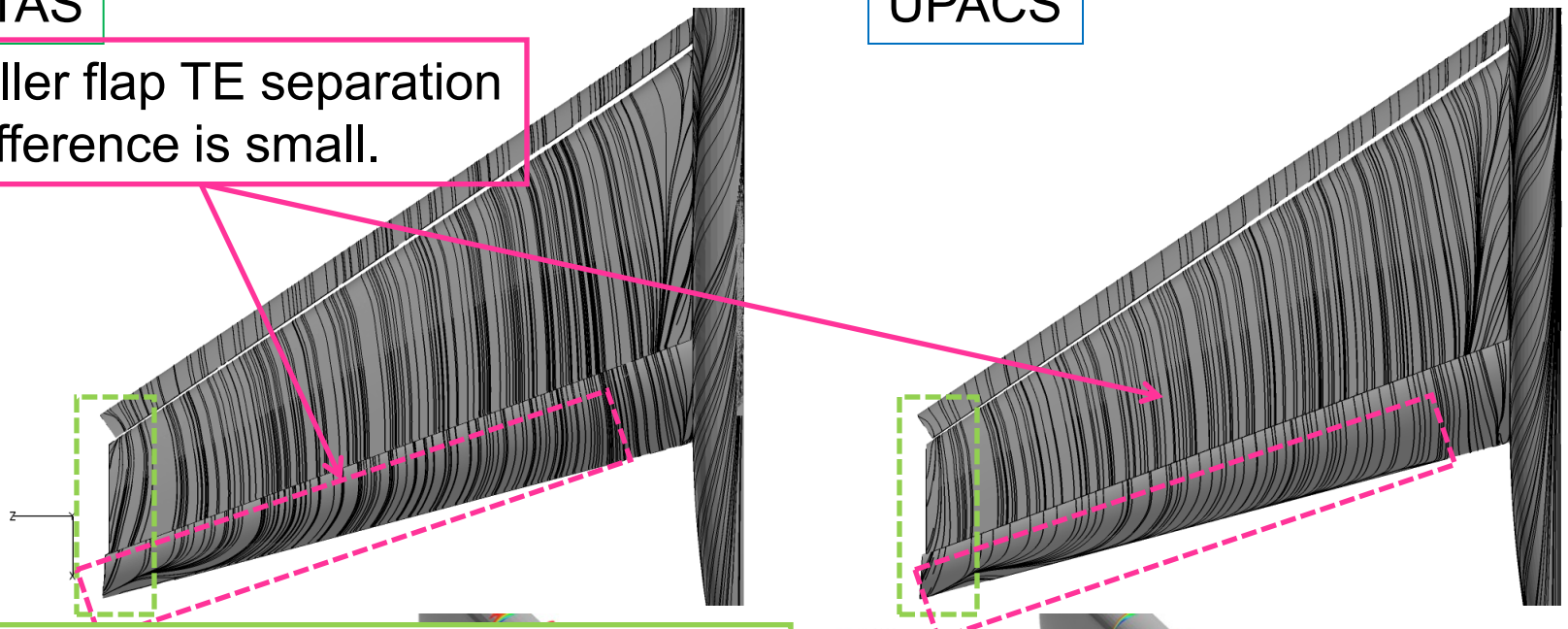
Oilflow and Ptotal at α=13deg by Medium grid (Left:TAS, Right:UPACS)

Case2:Oil flow and Ptotal (AOA=28, Medium)

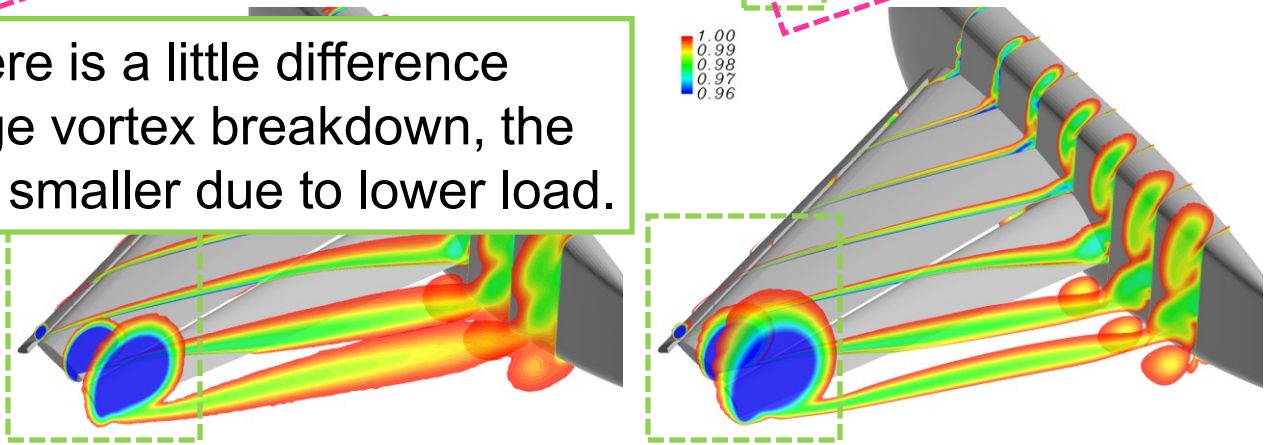
TAS

UPACS

Smaller flap TE separation
→Difference is small.



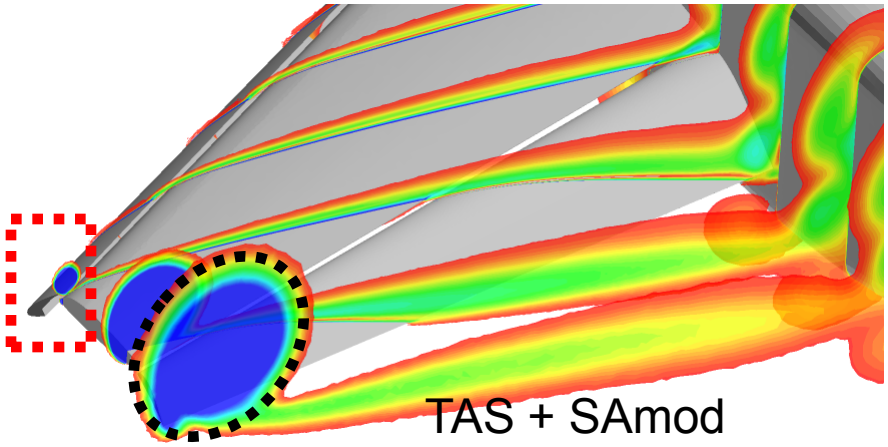
Although there is a little difference near the edge vortex breakdown, the difference is smaller due to lower load.



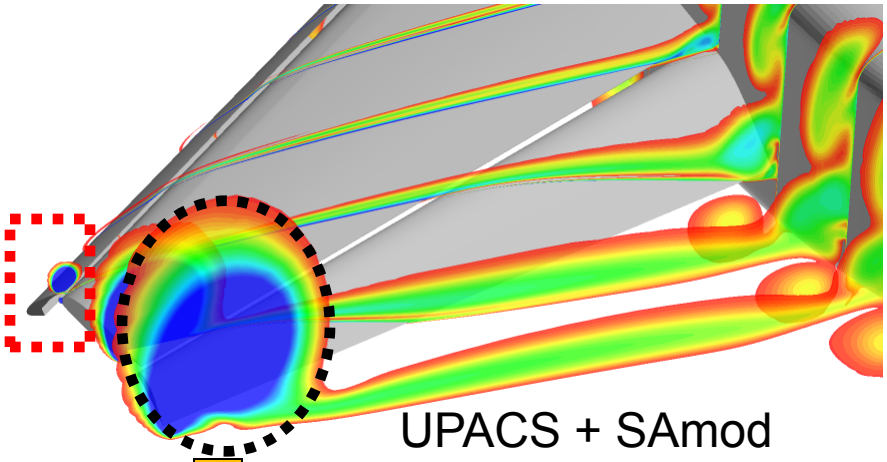
Oilflow and Ptotal at α=28deg by Medium grid (Left:TAS, Right:UPACS)

Comparison of turbulence model

- AOA=28
  - Influence on tip vortex behavior

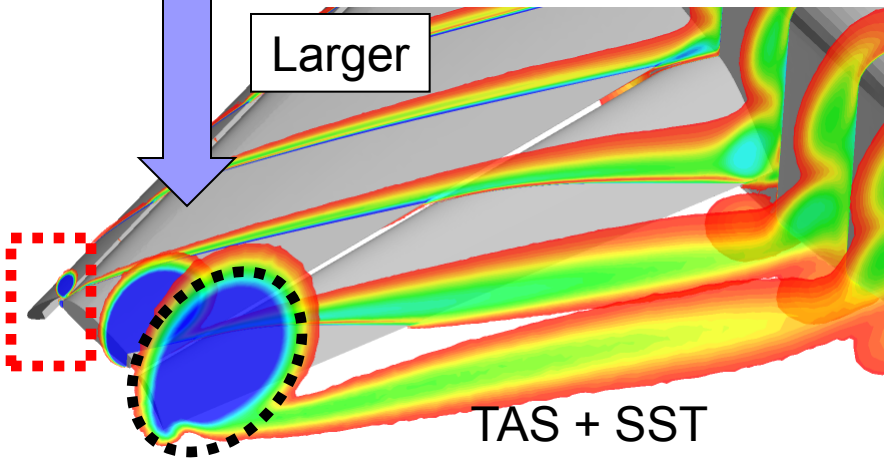


TAS + SAmod



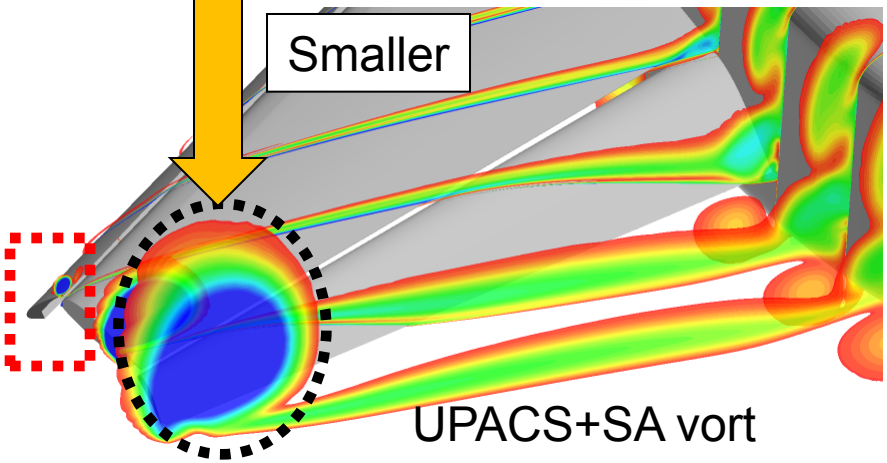
UPACS + SAmod

Larger



TAS + SST

Smaller



UPACS+SA vort

Pt on Medium grid (AOA=28)